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IN TWO SECTIONS

SECTION ONE

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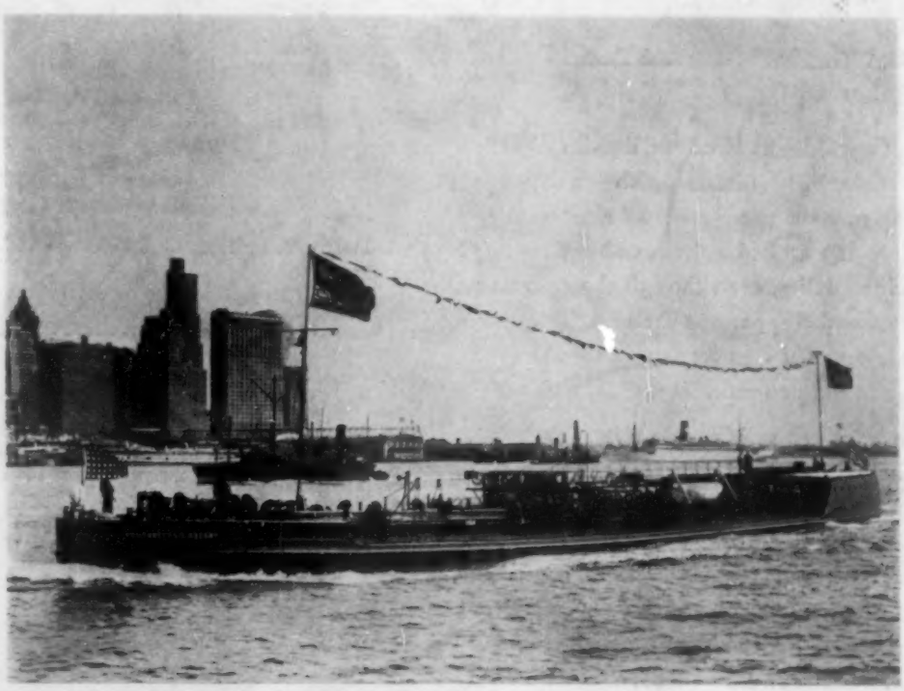

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THE
AMERICAN WELDING SOCIETY
JOURNAL

WM. SPRARAGEN, Editor | VOL. 14 | NO. 1

JANUARY

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Steel and Cast Iron in Stress-Transmitting Mechanisms*

By EVERETT CHAPMAN†

COMPARISON of the observed properties of cast iron and steel, simultaneous with an examination of their physical composition, throws a great deal of light upon the applications and limitations of the two materials. When the physical properties are interpreted in terms of physical structure, additional light is thrown upon the causes of failures of gross structures and upon the reasons for differences in the strength of various ferrous materials.

Consider the physical properties of commercial gray iron as explained by the microstructure of the metal, taking into account the chemistry of the material. Figure 1 shows a microphotograph at 100 diameters of unetched gray cast iron. It is an aggregate of pure graphite in flake form and impure steel. The graphitic flakes are pure carbon, generally in the form of shell-like plates. The steel matrix is an impure steel by commercial standards, containing relatively high amounts of sulphur, phosphorus and silicon, with a moderate amount of combined carbon. Like steel, this *matrix* has the modulus of elasticity of steel in that the number of pounds of stress per unit deformation has the same value as that of the open-hearth product, namely 30,000,000. The nature of the bond between the graphite and the steel in this physical aggregate is not known exactly, but it is undoubtedly poor as far as the transmission of a tensile stress is concerned. No bond is needed for the transmission of a compressive stress since the graphite flake perfectly fits its mating void and the bearing area between the two is fully developed.

* Paper presented at Annual Meeting, American Society of Mechanical Engineers, New York, N. Y., December 4, 1934.

† Vice-President, Lukenweld, Inc., Division of Lukens Steel Company.

Fig. 1—Unetched Gray Cast Iron. 100 X

Fig. 2—Illustrating Stress Distribution in a Celluloid Model Indicating Similar Action in a Cast-Iron Structure

Cast iron is, then, a spongy steel structure which is strong under a collapsing force only because its voids are filled with a material that supports the matrix. It tends to tear apart under the action of a tensile force, as though its voids were empty. Its microscopic behaviors from point to point are the actions governing its gross performance which, as measured in a tensile machine, is only a statistical summation. Consideration of these minute actions is necessary since many of the dynamic properties of a material, such as fatigue and impact, are influenced only by the value of maximum stress present in the material.

Figure 2 shows the stress distribution that exists in an elastic matrix similar to that of cast iron. It is a photograph of a piece of celluloid supporting a tensile load, taken under polarized light. In the celluloid, random shapes have been cut in a random distribution to simulate the location and shape of the graphitic flakes as they occur in cast iron. Assuming there is no bond between the graphite and the steel, this analogy is exact in the case of a piece of cast iron used for the transmission of a tensile stress. In compression, the analogy would be correct only if the holes were filled with a ma-

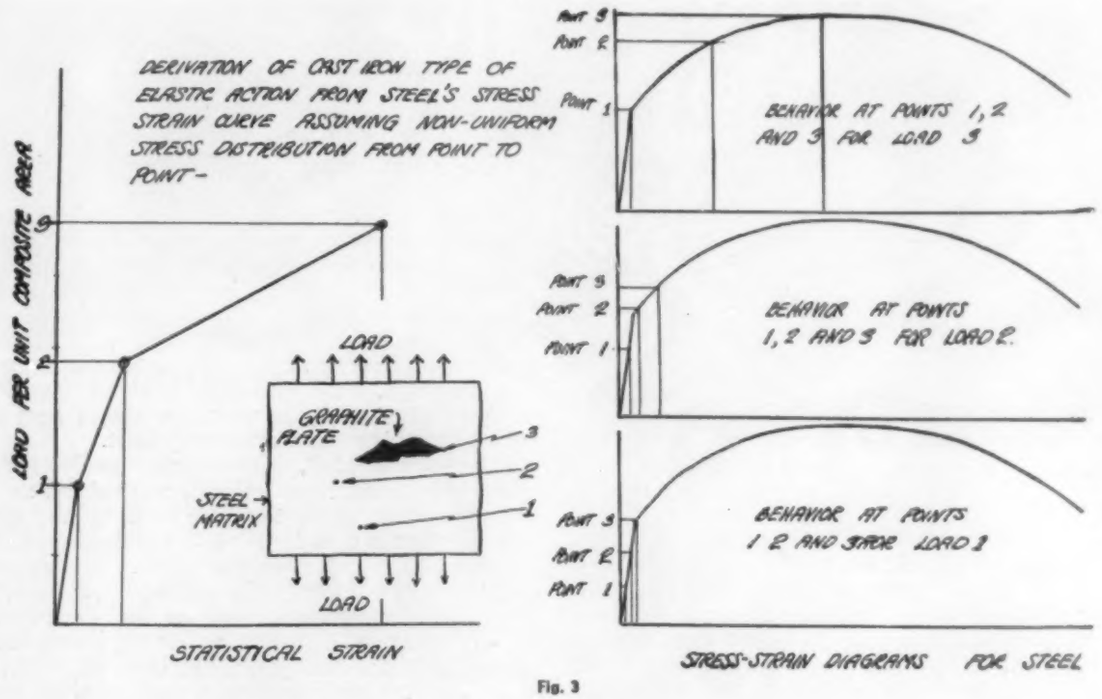
DERIVATION OF CAST IRON TYPE OF ELASTIC ACTION FROM STEEL'S STRESS STRAIN CURVE ASSUMING NON-UNIFORM STRESS DISTRIBUTION FROM POINT TO POINT-
LOAD PER UNIT COMPOSITE AREA
LOAD
GRAPHITE PLATE
STEEL MATRIX
LOAD
STATISTICAL STRAIN
BEHAVIOR AT POINTS 1, 2 AND 3 FOR LOAD 3
BEHAVIOR AT POINTS 1, 2 AND 3 FOR LOAD 2.
BEHAVIOR AT POINTS 1 2 AND 3 FOR LOAD 1
STRESS-STRAIN DIAGRAMS FOR STEEL

Fig. 3

terial that had a lower elastic modulus than the celluloid. Rubber would be such a material.

The photograph indicates that in such a configuration there is a tremendous variation of stress from point to point in the matrix. Many stress concentrations exist whose magnitude is from eight to ten times the values that exist at other points. These high stress values are present at the ends of the voids and are due to the fact that ripping actions occur at the ends of those sharp-pointed flakes existing at right angles to the stress. With such widely divergent stress values introduced by the presence of the graphitic flakes, it is interesting to note that the average stress, as calculated by dividing the applied load by the cross-sectional area, has very little meaning. The practice of working cast iron at as low a tension stress as has been proved necessary simply insures that the point of maximum stress is below the safe working limit for the material of the matrix.

In both gross structures and metals themselves, it is true that the stress in the main body of material must be reduced to such a value that the maximum stress existing at the point of greatest damage is safe for the material under its working load. Perhaps a reasonable view of the ordinary factor of safety is that it is a number which expresses a guess as to the number of times maximum stress exceeds the calculated stress in a structure.

It is obvious that a material with such incipient rips throughout its body will have poor tensile properties. The same material under compression will show much better properties if the severity of the incipient rips has in some manner been lessened. Impact values which express the tenacity involved in an energy-absorbing, ripping type of failure are obviously lowered in a material where the energy is absorbed at these few points of high stress rather than over a uniformly stressed cross-section. The fatigue characteristics of a material are a function of the material itself but they are also tremendously influenced by the points of high stress introduced in one manner or another. In a material in which the spread between maximum stress and minimum stress is as great as it is in cast iron, the fatigue values are much lower than those that would be exhibited by the matrix itself in a homogeneous form. It is interesting to note the relative insensitivity of cast iron to further notch effects. Highly refined steels, when properly treated, show tremendously high fatigue values when compared to cast iron, but in contrast to cast iron such steels must be fabricated with extreme care because their sensitivity to surface finish is great. Cast iron, with its myriad of notches already existing inherently, does not show the effect of one more point of high stress if it is introduced in the design.

Cast iron has a modulus of elasticity of 12,000,000 in contrast to the modulus of 30,000,000 shown by steel, a more homogeneous material of the same chemical composition as the matrix of cast iron. This low modulus, together with the fact that it varies with the stress, is again a result of the extremely heterogeneous stress condition, as already shown in Fig. 2. As a load is applied to cast iron, the material deforms elastically at some point and may deform plastically at other points. This combination elastic and plastic action is the mechanism operating to give the low modulus of elasticity in cast iron. It also explains the fact that the modulus actually drops as the stress increases. The stress in the steel matrix at one point may be very low and the corresponding deformation will be small. Points at the end of the graphitic flakes will be under a stress five or six times as great and the accompanying deformation will be five or six times as great as at the point of low stress. The statistical sum of all these varying deformations, as observed from the outside of the test piece, then determines a modulus of elasticity which of necessity is lower than that of the matrix itself in a homogeneous form. As the load increases, the point of low stress becomes a point of medium stress; the point which was previously highly stressed is a point at which the stress is now over the elastic limit. When this combination of elastic and plastic action is measured externally, the measurements are translated into a modulus of a still lower value. Here is an explanation of the reason why the stress-strain curve of cast iron is a curve that falls away from the stress axis, as shown in Fig. 3.

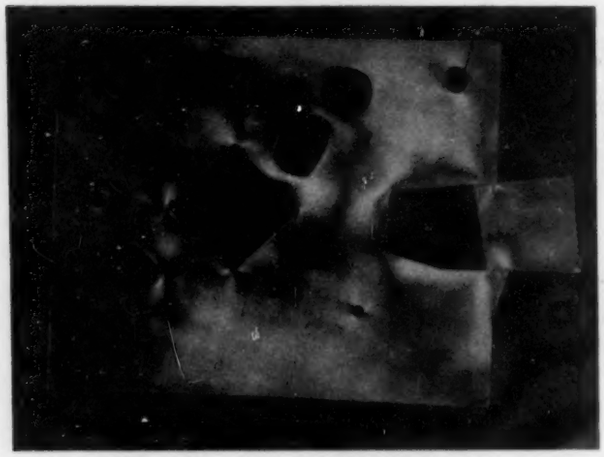

Fig. 4—Model Indicating Stress Concentrations around Openings

That plastic action at the points of high stress occurs early in the loading cycle explains why cast iron takes a permanent set at low values of stress. This fact, and the falling off of the value of modulus of elasticity at low load is indicative of the presence of terrific local concentrations of stress. The stress introduced by the smallest load is multiplied locally to values over the elastic limit by the discontinuities present.

Cast iron grows under repeated heating and cooling to a far greater degree than steel, because as the material expands under heat, the highly stressed points at the ends of the graphitic flakes are elevated over their elastic limit by the adjacent expanding material. When the iron cools down, these highly stressed points are permanently deformed in contrast to the points of low stress and the material exhibits the phenomena of a body assuming a size larger than it was originally.

If a bar of cast iron and a bar of steel, both of the same physical dimensions, are caused to vibrate with the same initial amplitude, the cast iron bar will cease vibrating before the steel bar. This physical fact connects with the same phenomena of heterogeneously stressed contours that is under discussion. The steel bar is truly elastic, provided the proportional limit has not been exceeded. The cast-iron bar is exhibiting combined plastic and elastic behaviors internally. The minute plastic actions or permanent sets that occur at the ends of the graphitic discontinuity are absorbing the energy of vibration in the form of heat. The transfer from potential to kinetic energy as the bar vibrates is thus performed inefficiently. As the vibrating bar passes through its central position, its energy is all kinetic, or one of motion. As the bar gradually deflects into its position of maximum deflection, this kinetic energy of motion is gradually transferred into the potential energy of a stressed material. As the deflection becomes greater, the points of high stresses within the material are the first ones to be permanently deformed since they are the first points to exceed the proportional limit. This energy of permanent deformation will appear in the form of heat and is thus lost to the vibrating system. A vibrating system will have a high decrement if at some point in the system there occurs a transformation of energy into heat. This is exactly the mechanism of the damping properties of cast iron. There are points within cast iron which, as the material vibrates, are not capable of throwing the energy back and forth from potential to kinetic since these points cease functioning elastically at some point of the cycle. These are the points of high stress at the ends of the graphitic flakes. It is as though, in the case of the steel bar, the initial deflection that started the vibration was of such magnitude that the bar was permanently bent.

A low-carbon steel, with chemical analysis identical to the steel matrix in cast iron, will exhibit an elastic homogeneity in which the ratio of maximum stress to average stress is very low, due to the absence of internal discontinuities that raise the stress. Because of this fact, the steel will show values of impact, fatigue, tensile strength and modulus of elasticity that are superior to those of commercial gray iron. Average stress in a bar of steel, as calculated by dividing the load by the cross-section, is a far more accurate evaluation of the point-to-point behavior in a piece of steel than it is in cast iron. The elastic range in steel is divorced from the plastic range because the stress values from point to point are more nearly of equal value. The stress-strain characteristics of cast iron, and all the physical properties of cast iron, can be explained in terms of the simultaneous occurrence of elastic and plastic actions. This is another way of saying that a given load upon a non-homogeneous material gives rise to values of stress that are widely different at adjacent points.

A crude analogy of this mixture of behaviors is afforded by the action of a steel test bar under a tension load in which the alternate sections are respectively $^1/_8$ in. in diameter and 1 in. in diameter. Assume that the average stress in the bar is obtained by dividing the total load on the bar by the average area of the two respective cross sections, such a bar would have high values of stress adjacent to low values of stress in the ratio of 64 to 1. This bar would exhibit very poor tensile impact values as compared to the same amount of material distributed in a uniform manner since all the energy would be absorbed by the small diameter section which is the section of high stress. This small section is the equivalent of the highly stressed portion at the ends of the graphitic flakes in cast iron. The fatigue characteristics are bad since the fatigue strength would be determined by the stress 64 times as great as the stress in the large section and roughly 25 times the stress over the average cross

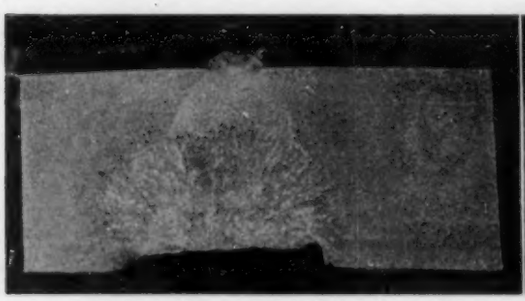

Fig. 5—Poorly Made Weld—Undercut

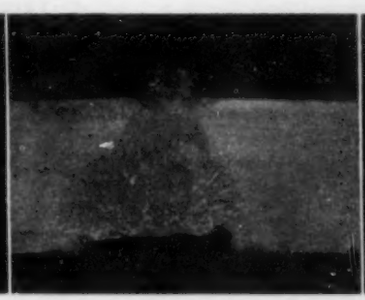

Fig. 6—Undercut Weld and Bad Root Formation

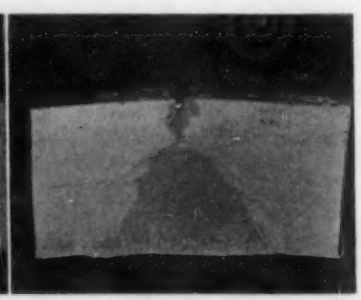

Fig. 7—Incomplete Penetration

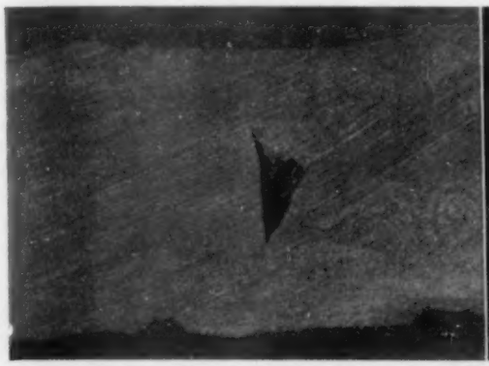

Fig. 8—Void in Center of Weld

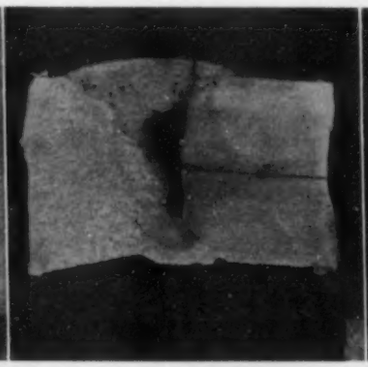

Fig. 9—Porous Weld

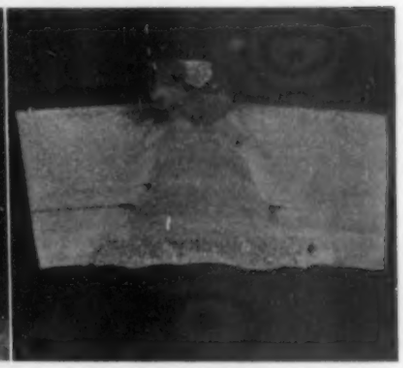

Fig. 10—Bad Steel

section. The stress-strain curve of such a bar, as determined in the tensile testing machine, would be a curved line since the small diameter portion would reach its elastic limit and act plastically while the large portion of the bar was still in the lower portion of the elastic range and exhibiting the usual modulus of steel. Such a bar, used as a vibrating reed, would have a high decrement or damping coefficient since under a reasonable initial deflection the small portion of the bar would bend and absorb energy while the large portion was stressed well within its elastic limit. The bar would exhibit a poor tensile strength compared to the same amount of material uniformly distributed because the strength would be that of the small portion rather than that of the larger bar.

This analogy presents the phenomena of a material with the elastic properties of steel exhibiting the elastic properties of cast iron by virtue of the presence throughout its volume of a series of random discontinuities. The resulting mechanical properties of this bar, and of the cast iron, can be completely explained in terms of the high ratio of maximum to minimum stress that results.

This conception is by no means limited to the explanation of the behavior of structural materials. Any sort of a structure that is subjected to a load will, at a point of severe change in contour, exhibit poor tensile, fatigue, impact and related properties. Figure 4 is a photo-elastic study of a celluloid plate in which holes and throats of various shapes and sizes have been cut. A wedge has been driven into the mouth of one of the U-shaped throat openings to load the structure. Inspection of the photograph shows that the homogeneous elastic action of this plate has been sadly upset by the presence of the voids and discontinuities that have been introduced. It shows that the corresponding steel plate will not exhibit the properties of the parent material at the several points where the stress has been raised. Visualizing the type of elastic discontinuities that exist in a riveted structure, for example, it is no wonder that the smooth-flowing welded structure, with its uniform butt joints and carefully faired intersections, offers all the rigidity, energy-absorbing abilities and high fatigue values that are inherently guaranteed by its high degree of elastic homogeneity.

The shape of internal voids and surface defects has a tremendous influence on the mechanical properties. Malleable iron, in which the graphite is in spherical form, has much better properties than gray iron of identical chemical composition. The stress concentration which is introduced by a spherical void is theoretically equal to $2^{7}/_{10}$ times the magnitude of the average stress, whereas the intensity of stress introduced at the ends of one of the sharp cornered graphite flakes in cast iron may be of the order of magnitude of ten times the average stress. Modern electric furnace cast iron that has been superheated has finely divided graphite flakes instead of the coarse flakes found in the cupola product, and all the physical properties of such modern iron—even modulus of elasticity—increase in the same ratio as the maximum stress is brought more into line with the average stress by this re-distribution of the graphite.

The difference between the transverse and longitudinal properties of wrought iron is another phenomena of the strength of materials that illustrates nicely the effect of the shape of inclusions. In wrought iron, the pure ferrite matrix is riddled with long, slag streamers that have a most decided orientation along the length of the plate as it was rolled. When the stress is parallel to these streamers, the elastic behavior is four or five times as good as it is when the stress is at right angles to the slag inclusions, since a load at right angles to the slag inclusions is in the direction to exercise the maximum ripping effect in the ferrite at the ends of the slag voids. The maximum stress in the material is much greater for a transverse pull than it is for a longitudinal pull.

Fig. 11—Good Weld in Poor Steel

Fig. 12—Good Weld in Good Steel

The possibility that the average stress equals the maximum stress in an ideal material leads to some interesting conjectures on the possible strengths of materials. Steel is by no means the pure, homogeneous material that it is usually visualized. If graphite distributed at random can so vitiate the known properties of the steel matrix in cast iron, what strengths would steel exhibit if it, in turn, were rid of the minute impurities, minute internal checks and internal strains known to exist in the commercial product? The cohesive forces between the atoms making up a material is a measure of its theoretical strength. This atomic bond can be calculated from a laboratory measurement of the latent heat of vaporization of a given material and, assuming that the same degree of cohesion exists at room temperatures as exists at the vaporizing point, will give a value for the atomic bond of at least the right order of magnitude. Griffith, in England, measured these values for common glass. It was chosen in his experiments because the phenomena of plastic action was not present to confuse the behavior of the tensile specimens. The measured strength of the glass chosen was 25,000 lb. per square inch. This is the average statistical strength of the gross mass with all its internal discontinuities and internal strains as present in a tensile test bar. The atomic forces, as measured by the latent heat of vaporization, demanded that the material show a strength of around 500,000 lb. per square inch. Griffith then broke fine threads of this material, measuring the stress at rupture. Fragments of the same thread were then broken and measured, and the fragments resulting from this test were again broken and measured. He was selecting his final test specimen as that fragment which outpulled all the cross sections that had failed during the test. His final test specimen, thus selected on the basis of tensile elimination of internal flaws and defects that tended to raise the average stress, broke at a stress of 491,000 lb. per square inch. This is a remarkably interesting indication of the possible strength of materials in the homogeneous state. It is a poignant illustration of what a wide spread between maximum and minimum stress will do to either an engineering material or an engineering structure. The ratios involved in Griffith's experiments are also a measure of the progress that is still to be made in the manufacture and use of structural steel. After all, a severely notched punch press, a poorly welded joint, a piece of cast iron, a piece of dirty steel or a riveted lap joint are all examples of material that has been victimized by either man or nature in that the stress distribution has been made extremely non-uniform. It is due to the points of maximum stress that the inherent abilities of steel are not more fully realized, that materials cannot be worked at higher loads and that factors of safety must be what they are.

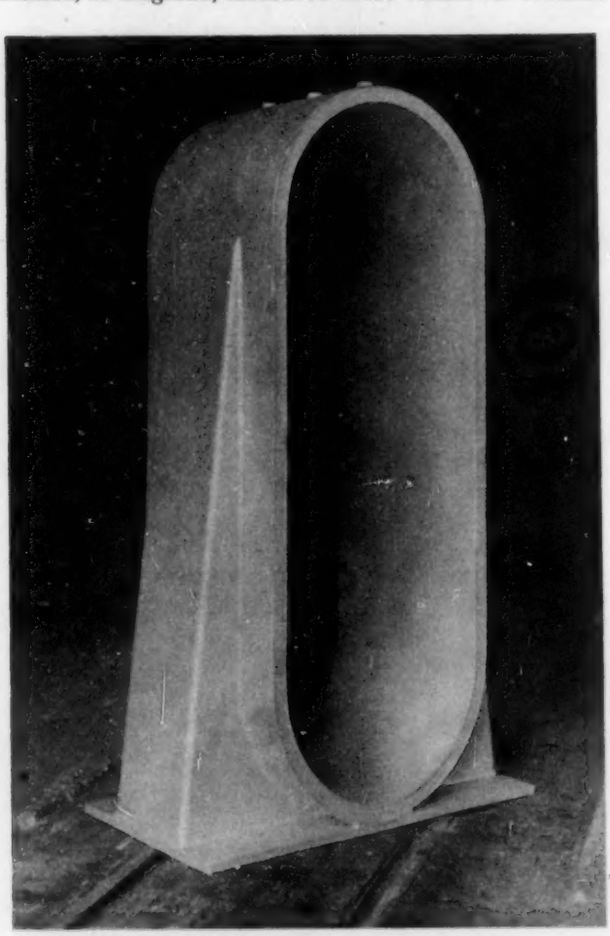

Fig. 13—Welded Steel Frame for a 2000-Ton Hydraulic Press

The atomic bond in pure iron, as theoretically deduced from its latent heat of vaporization, indicates that the strength of steel should be about ten times the observed values in ordinary commercial steel. The difference between the observed values and the theoretical values can be reasonably supposed to be due to stress-raising, non-metallic impurities, minute internal cracks resulting from cooling, and internal strains distributed at random that pre-load the material from point to point. Is it not reasonable to conceive that the known strengths of materials and structures are the difference between the theoretical strengths of the atomic bonds and the damage done by such minute phenomena as notches, non-metallic impurities, distributed graphite, screw threads, unfused roots of welds, sharp fillets and all such forms of discontinuities.

Modern weld metal is a freak. Its properties seem to give a clue to what might be expected from theoretically clean materials. It is perfectly possible to produce in the electric arc, in the form of weld metal, a steel with carbon content of 0.08%, tensile strength of 65,000 lb. per square inch, and an elongation of 35 per cent in 2 in. These properties, furthermore, are shown in the cast condition and material of the same analysis made in the open hearth by modern steel-making practices will not begin to show, in any respect, the physical properties of the weld metal. The essential difference seems to be: first, the treatment of minute drops of metal; second, the use of well-designed slag; third, exclusion of the atmosphere; and fourth, temperatures much higher than can be obtained in the open hearth. The resulting metal is much cleaner than commercial open-hearth steel and it is not a coincidence that its physical properties are superior to open-hearth steel of equivalent chemistry.

The commercial existence of such a metal, together with the fact that it can be used to integrate rolled steel, has several important implications for the designer of structures and the makers of steel. The freedom of welded design inherently implies the ideal structure, with its smooth-flowing contours and its homogeneous, elastic properties. That such material as modern weld metal can be produced is an incentive to both the maker of steel and the designer of structures to reduce, perhaps eliminate, the number of damaging discontinuities in their steels and their structures. Without investigating the feelings, mathematical treatments and experimental methods that distinguish the master designer, it may be pertinent to illustrate some of the abuses of welded

joints that tremendously detract from the efficiency of a welded structure.

Figure 5 pictures an etched cross section of a poorly made weld. It has been severely under-cut at one edge. The maximum stress that exists at the root of the under-cut is the stress that determines the important structural properties of the joint. The efforts of the steel maker to produce a good steel, the efforts of the electrode manufacturer to produce good electrodes and the careful work of the designer to produce an ideal structure have been completely nullified by the presence of the under-cut.

Figure 6 illustrates an example of welding that, if used under load, will entirely discredit the use of weld metal wherever such practice is found. The weld is under-cut on the side from which the metal was deposited. The drippings of hot metal on the far side are not only badly oxidized, because they lack the protection of the electrode, but also form a discontinuous projection which will introduce a high root stress. The designer's factor of safety covering this joint will have to be great enough to reduce to a safe value either the stress at the root of the under-cut or the stress at the root of the oxidized projection, taking into account the damaged metallurgical condition of the drips.

Figure 7 is an example of a weld that has not completely penetrated to the far side. The incipient rip, introduced by the unfused root, reduces the working strength of such a joint by at least six times.

Figure 8 shows a welded joint made from both sides in which the workmanship was such that neither the weld metal nor the steel has an opportunity to perform as a homogeneous, elastic entity. The fusion at the root of the weld is incomplete, introducing a void at right angles to the applied load that is as bad or worse than any maximum stress condition that could be introduced by graphitic flakes.

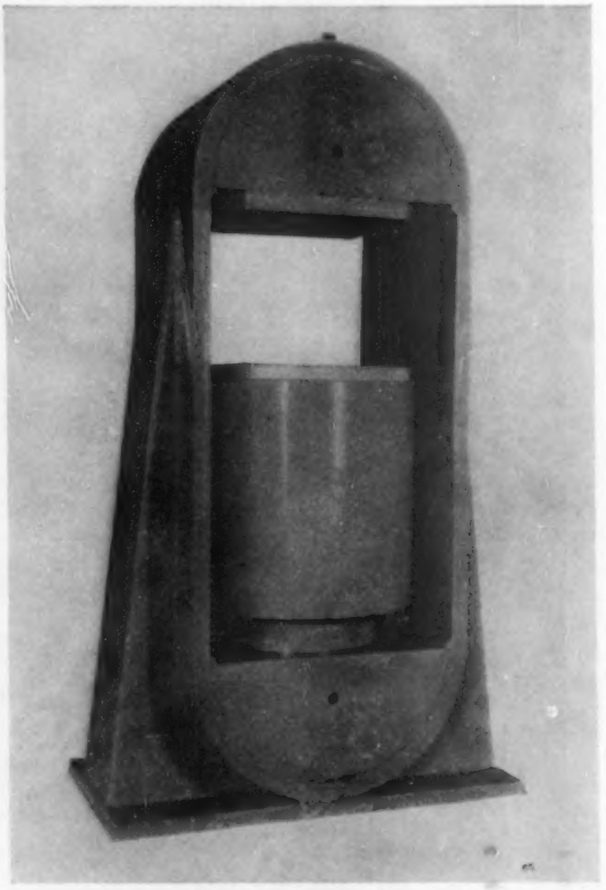

Fig. 14—Semi-Circular Slugs of Cast Iron Inserted

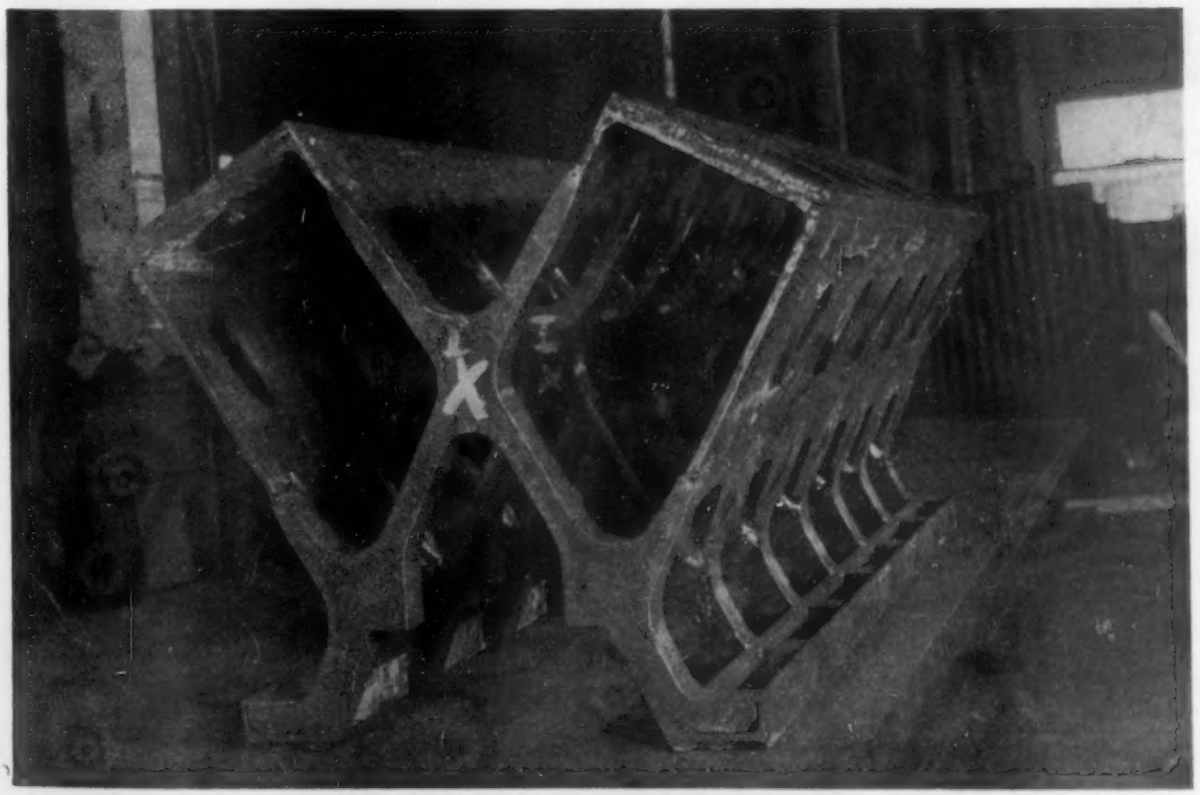

Fig. 15—Main Load-Supporting Element for a Diesel Engine Frame

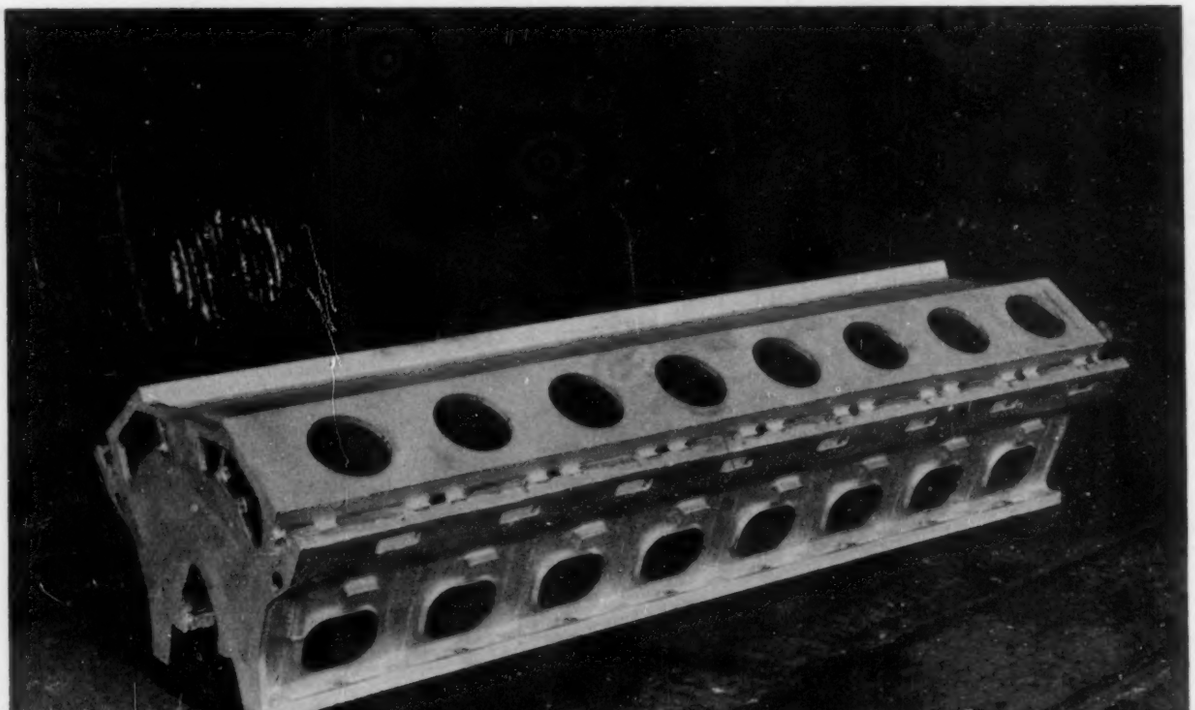

Fig. 16—Completed Engine Crankcase

Figure 9 is another example of the same type of workmanship in which not only did the incomplete fusion result in failure but the perfection of the weld metal has been entirely nullified by the porosity present. The porosity was due to the fact that the electrodes were not used at their proper current density.

Figure 10 illustrates a welded joint in which a combination of troubles is present. The weld has been attempted entirely from one side which results in the usual oxidized projection of metal on the far side. In addition, the steel itself was not properly adapted for ideal welding. It exhibits a layer of gas-forming impurities which, under the heat of the arc, produce great volumes of gas, generally in such large quantities that the electrode, with its normal boiling action, could not eliminate them. This joint again illustrates the abuse of material with excellent physical properties in conjunction with a parent metal that is not the equal of the material used for joining.

It is possible to make a good weld on poor parent metal if the proper technique is observed. Figure 11 shows a sound, homogeneous weld made on a parent steel of poor welding properties. The parent metal exhibits several banded zones or laminations containing non-metallic impurities which, under the heat of the arc, will give rise to volumes of gas, some of which will be entrapped.

Figure 12 demonstrates what can be expected today in a welded joint when the proper steel specifications and welding technique are observed. The joint as a whole presents very little change in either external or internal contour. The stress condition over such a joint would be extremely uniform; there are no points of maximum stress of any magnitude. The metallurgical discontinuities that exist in such a joint, due to the thermal abuse of the arc, form different subject matter but they can, however, be corrected to produce complete homogeneity.

With the welding technique and the parent metal specification definitely known for the production of the type of joint illustrated in Fig. 12, it remains for the designer to evolve the ideal structure to meet the mechanical demands imposed by his problem.

Figure 13 illustrates a welded steel frame for a 2000-ton hydraulic press. Although a load of 2000 tons is working on the steel side members of this frame, a flat butt joint, properly made, gives the ideal type of joint contour. The parent metal was carefully specified; fusion at the root of the weld was absolutely insured by chipping out the back of the first bead; the contours of the finished bead were carefully ground where they presented any discontinuities; and the entire frame was heat-treated to restore those physical properties that suffered because of the welding heat. The design of the press frame is such that the steel is used in pure tension, which is the ideal use for any homogeneous material, while the mechanical requirements of distributing the load from the bottom of the hydraulic cylinder to the steel hoop were met by the use of semi-circular slugs of cast iron in compression, as shown in position in the frame in Fig. 14. Here again utility and economy dictated the use of cast iron because it shows desirable properties in compression, and that, together with its low cost, made it an ideal material for this application. Such a construction as this minimizes the curvilinear type of deflection that usually occurs in press platens. The curvilinear type of deflection is extremely hard on dies or other equipment that depends for support on the rigidity of the platens. The only type of deflection of which this press is capable is a straight tension elongation of the side members, which is an elastic motion parallel to the motion of the hydraulic cylinders and therefore does not affect die alignment.

Using selected specified steel of the known and homo-

geneous characteristics and using welding technique with governing specifications guaranteeing the solidity and homogeneous elastic nature of the joint, together with the selection of a type of welded joint which does not incorporate internal discontinuities, and with proper supervision to insure compliance with the approved technique such a structure may be designed for a working stress of a value that is 75 per cent of the yield stress of the steel. This is a factor of safety of one and a third based on the yield point. The uncertainty involved in not working the steel at the yield point is due to mechanical considerations of possible over-loads. Knowing that there are no incipient rips in this structure of the usual order of magnitude and having selected a design with a type of deflection that is not detrimental to the operation of the machine, there is no reason why the material should not be worked at a stress that is just under the yield strength of the steel. Any attempts to work it over the yield strength of the steel will, of course, result in a plastic deformation each time the load is applied.

Figure 15 is another example of a structure produced by welding in which the maximum effort was exerted to eliminate all internal and external discontinuities and severe changes in contour. It shows the main load-supporting element for a Diesel engine frame in which the requirement of light weight is combined with the necessity of sustaining, over a service life of many thousands of hours, a load of the nature of pure impact. This is simply saying that the design must be very clean and the factor of safety must be very low in order to meet this severe duty with minimum use of material. The gas load of 38,000 lb. is applied at the bolt circle holding the cylinder head to the top deck and the reaction to the gas load occurs at the large studs that secure the main bearing cap to the frame. The problem is further complicated by the fact that this is a V-type engine. The loads in opposite cylinders occur in different portions of space and must be transmitted to a common reaction point, namely, the crankshaft, and this means that an intersection occurs between two pieces of metal carrying tension.

In the production of the main frame member, flame-cutting was employed in order to provide generous, easy-flowing changes of contour in the cromansil steel at this intersection. Machining was used in order to produce a generous curve at the point of intersection of the top deck and the side sheets. It is sound practice in a structure of this character definitely to control these critical sections, and welding in general cannot be relied upon to produce a predictable contour in a corner. A careful technique must be specified and supervised in making the joints between the component parts in order further to insure the absence of uncontrolled boundaries, either internal or external. Once this procedure has been followed, the only limit to the lowering of the factor of safety is the residual uncertainty as to how far this process has been carried not only in the construction of the piece but also in the actual selection of the steel entering into the structure. In the ultimate then, the strength of a structure could increase indefinitely in proportion to the cleanliness of the materials and cleanliness of the design.

Figure 16 is a view of the completed engine crankcase with all the pads, camshaft bearings, timing gear bosses and oil return drains that are necessary for mechanical operation of the engine. The very requirement of the presence of these appendages to the main structure is again a hazard involving the factor of safety, since care must be taken in securing these pieces to make sure that they again do not introduce some abrupt change of contour or internal boundary on a highly stressed member.

Rebuilding Pulp Grinder Shafts

Application of Wear-Resisting Bronze Eliminates Troublesome Effects of Corrosion

By HARRY A. WALKER† and D. S. LLOYD†

IN PAPER pulp mills, the steel shafts in pulp grinders, which vary in diameter from 8 in. to 15 in., are continually worn away at the threads on which are held the cast collars which in turn hold the stone. It is believed that this wear is caused largely by the corrosive action of very dilute acid products from the wood. When any appreciable wear has taken place, it is difficult to keep the collars drawn up tight and any slight play further accentuates the wear, until finally it is necessary to replace the shaft and, in some cases, the collar.

For many years the practice was followed in some mills of starting with a full-sized shaft and when this was worn turning it down to a smaller size, refitting collars and bearings accordingly. This was done in some cases four or five times until the shaft which originally was, say, 12 in. in diameter, finally was used at 8-in. diameter and after that was discarded. Naturally the cost of changing the bearings and other parts to allow the use of these shafts of varying diameters was considerable, to say nothing of the investment in the bushings which were required when the shafts were used at less than the full original size.

It was natural that welding should be considered as a method of reclamation in a case of this kind. Not until the development of a special bronze rod for oxyacetylene welding particularly adapted to building up successive layers on steel did this operation attain its present state of perfection. This new bronze rod has several outstanding properties which distinguish it from rods which have been used in the past. Not only is it particularly adapted to building up a deposit in successive layers but, because it contains deoxidizing elements, the fuming during welding is reduced very considerably. This allows the application of the bronze without discomfort to the operator and increases the speed of deposition.

† Dominion Oxygen Company, Ltd.

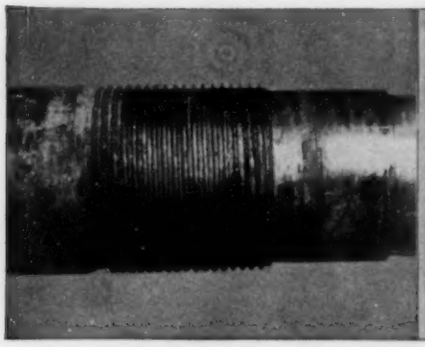

Fig. 1 (Left)—Section of Grinder Shaft Showing Badly Worn Threads

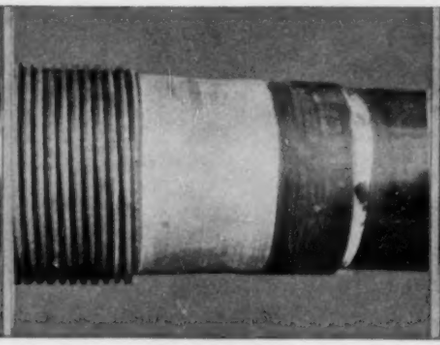

Fig. 2 (Center)—The Threads Have Been Removed and the Surface Undercut Ready for Welding

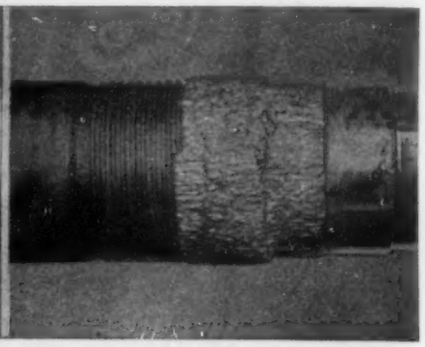

Fig. 3 (Right)—The Worn Areas Completely Built Up with Bronze Weld Metal

This new rod gives a much higher tensile strength both in the weld metal and in the bond between the bronze and the steel (over 50,000 lb. per sq. in.) and has the wear-resisting properties of the best manganese bronze.

Procedure for Building Up Shafts

The actual principles of building up these shafts with bronze are comparatively simple and practically the same as for any other bronze-welding operation. The shaft must be cleaned thoroughly at the point which is worn and set up in perfect alignment and in such a manner that it may be turned during welding. The cleaning is accomplished by turning off the old threads and worn packing gland surface down to clean sound steel. The steel is turned down $^3/_{16}$ in. below the base of the threads in order to get down to absolutely sound material, and to eliminate any chance of surface cracks, thread fractures, etc.

In some cases the shaft is left in the lathe during subsequent preheating and welding, care being taken to release the lathe centers as the shaft expands, the shaft being supported by suitable vee blocks or dollies. A temporary preheating furnace is built around the portion to be welded and a charcoal fire or gas- or oil-preheating torches used to bring the shaft to a black heat. This preheating must be uniform around the shaft. It not only serves to eliminate any possibility of warping but also makes it possible to apply the deposit faster with resulting economy in labor and gases. A suitable flux must be used and the bronze applied in successive layers after proper and careful bonding is obtained with the steel.

The first illustration shows a worn shaft as it is taken from the grinder after service. It will be noted that some of the threads have been worn down considerably and the diameter of the shaft at the end of the threads is less than the main portion. The shaft is set up in a lathe and the worn threads and surface completely cut off as shown in the second picture until the surface exposed is clean bright metal.

Another illustration shows the shaft after welding has been completed and the preheating furnace has been removed. It will be noted that the bronze has been deposited in strips and to a thickness such that the diameter of the shaft is slightly greater than that required when finished. This allows for the turning off of the slight unevenness in the layers and gives a perfectly finished job. The threads are subsequently turned in a lathe in the usual manner, but they are now completely cut in the deposited bronze. These bronze threads last longer and give even more satisfactory service than the original steel threads cut in the shaft itself when it was new.

The figures for the reclamation of one of these shafts provide some interesting data on the cost of the work. The shaft was 15 in. in diameter and weighed approximately $4^1/_2$ tons. The threads were 1 in. deep, $^3/_8$ in. thick and $^7/_8$ in. pitch. The machine work necessary for the removal of the worn threads and undercutting to a depth of $^3/_{16}$ in. below the threads and the packing gland surface required 2 hrs. Another $1^1/_2$ hrs. were consumed in preheating. In this case this was done by means of a hand torch. The actual welding was carried out in 9 hrs., using 70 lb. of bronze rod; $1^1/_4$ in. of bronze was applied to the threaded section and $^3/_8$ in. to the packing gland surface. The final finishing and threading took an additional 4 hrs., or a total of $16^1/_2$ hrs., to complete the work on one end of the shaft.

One of the outstanding merits of this method of reclamation is that it can be repeated over and over again. When the rebuilt bronze threads are finally worn down by the corrosive action in service, the shaft may be rebuilt in exactly the same way after the corroded metal has again been turned off. As the new bronze welding rod forms an excellent bond with previously deposited bronze, it is necessary to remove only the corroded metal. Some mills have already rebuilt the same shaft several times and there is no reason why this cannot go on indefinitely, thereby eliminating the replacement cost of grinder shafts entirely.

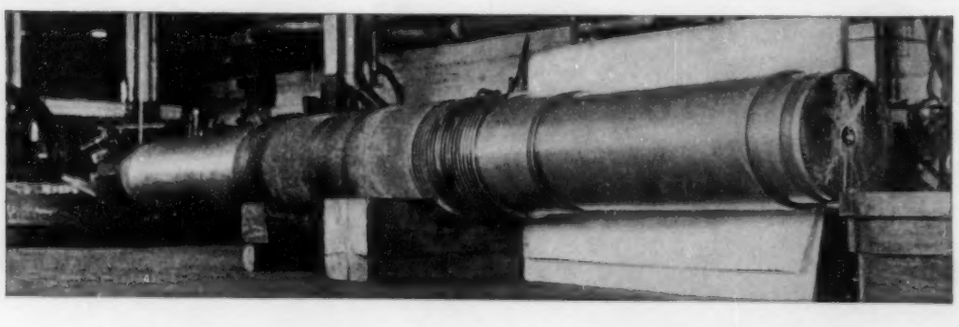

Fig. 4—The Finished Grinder Shaft with Both Ends Restored Is Ready for Service Again

Economy in Welding Designs*

By HOWARD G. MARSH†

ECONOMY or efficiency in the design of welded structures is absolutely essential, for if such structures cannot be made competitive with cast structures, they will not be used. In some structures welded construction has a wide margin in cost over cast construction and in such cases the refinements of design which effect savings are not so necessary, but with the increase in the number of welderies being established the competition to be met includes not only cast construction but other welded construction. It is, therefore, important that every design should be carefully scrutinized to effect every saving possible.

Assuming the designer is experienced in machine construction, then the two most important fundamentals of this medium are: first, a good general knowledge of welding and second, a knowledge of the material—rolled steel. It is the second item that will be stressed in this article.

It is not only important for the designer to think in terms of rolled steel sections but also in terms of the rolled steel sections in such sizes and shapes that they will take the base price, or with as few extras as possible.

Choice of Materials

In choosing materials a great variety is available, which includes billets, slabs, structural shapes, bars of all descriptions, pipe, forgings, special rolled sections and steel castings. There is a great difference in the price per pound of these materials and certain facts regarding their surface, size, cutting tolerances, etc., also have an important bearing on their use.

Extras and Tolerances

The steel manufacturers publish a book entitled, "Uniform Extras and Deductions for Products of the Iron and Steel Industry under the Code of Fair Competition." This book contains many surprises for the designer who is not familiar with mill practice or the pricing of rolled steel products. He will be introduced to the word "Extras," and before getting very far in the book he will no doubt wonder if any steel is sold at the base price. The book will explain why in a recent inquiry one item involving a piece of steel $^3/_4$ of an inch thick was priced at approximately $140 a ton and another piece $^3/_4$ of an inch thick at about $24 a ton. This book gives in detail the various extras and the standard mill practice as regards permissible variations in thickness, length, width, flatness, camber, etc., for hot-rolled steel products.

In their desire to keep inventories at a minimum there is a tendency among the machinery builders to order only enough steel to build a certain machine. The result is their inquiries consist sometimes of a list of items cut to the exact size and shape required. While this saves them considerable flame cutting and entails no scrap loss or the purchase of excess material, it may not be the economical way to buy the steel required for the job. This is not so true of structural fabricators who have entered into the welded machinery field, as they have had more experience in purchasing this material and usually carry some in stock.

What the Designer Should Know

Purchasing agents are usually more or less familiar with extras and tolerances of the various products, but it is the designer who should have this information. If the bill of material contains an item of 6 in. by 6 in. square of any given length, the purchasing department will simply get the best price for that item and there is a possibility that the quotation may be on a 6-in. by 6-in. forging, which, of course, takes a comparatively high price. It is possible, however, that a 6-in. by 6-in. billet, which is a low-priced material, would do for the part, thereby effecting a considerable saving. That question would be up to the designer and to decide it intelligently he should know what a billet looks like.

If the requisition for a given structure contains several rectangular pieces 3 in. thick and they come from a plate mill, each piece will be considered as a separate item and the customer will be charged 45 cents per lineal foot for the flame cutting of all four sides of each piece. When two rectangular pieces of the same width are ordered as separate items, it means four flame cuts across the width of the piece, whereas if they are combined and ordered as one piece, it means only three cuts across the width of the piece, one of which is made in the customer's shop. If the pieces are not rectangular in form there will also be sketch extras in addition to the flame-cutting charges. Therefore, it is apparent that it may often be desirable to combine items of the same thickness even if it involves ordering extra material, for the designer knowing this can probably change the design of some part to utilize this extra material.

The flame-cutting tolerance on a 3-in. plate is plus $^5/_8$ of an inch and, while this is perhaps as close as can be expected at a rolling mill, it is not always close enough for machine construction and may involve extra machining or re-cutting at the customer's plant. This is sometimes an additional reason for the customer combining items, as it enables him to cut closely to dimensions where it is necessary. These facts should be known by the engineer, for the savings they may accord the customer are only possible if they are kept in mind in the early stages of design.

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* Paper presented before Pittsburgh Section, A. W. S., April 18, 1934. In this article, Mr. Marsh discusses a subject on which practically nothing has been published heretofore, but with which every manager and designer should be thoroughly familiar in order to produce the most economical and acceptable welded designs. That not only engineering but also economics enters into the successful welded design is convincingly shown by the various practical examples.

† Assistant Manager Specialty Sales, Carnegie Steel Company.

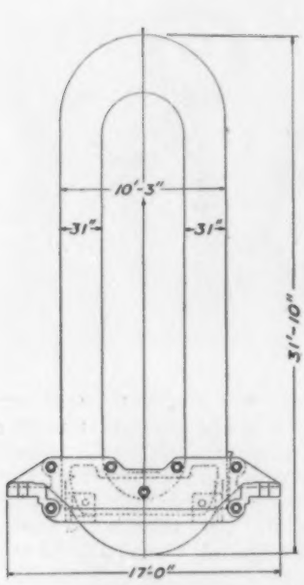

Fig. 1—Side View of Fabricated Steel Mill Housing

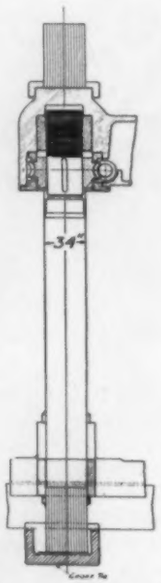

Fig. 2—Preliminary Design, Using Sixteen 2-in. Plates, Flame Cut and Welded along Edges

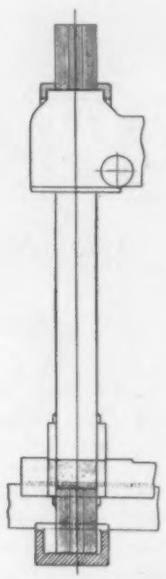

Fig. 3—Preliminary Design, Using Thirty-Two 1-in. Plates, Flame Cut and Welded along Edges

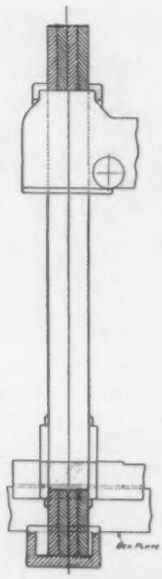

Fig. 4—Adopted Design, Using Four Forged Slabs Each 8 in. Thick, Flame Cut and Welded along Edge,

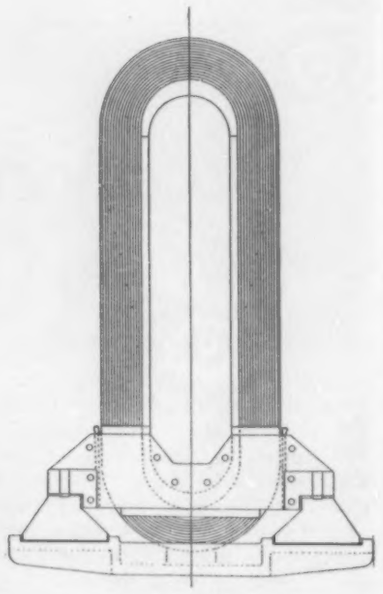

Fig. 5—Preliminary Design Using Successive Layers of Welded Links Shrunk on a Core

Most Economical Material to Order

When the design has been worked out in a general way the question of materials should be investigated and, if possible, the design modified to utilize the lowest priced material consistent with good design. A study of the Shape Books and the Standard Classification of Extras, put out by the various steel manufacturers, will probably indicate how this may be done, or the question may be taken up with the steel manufacturer. The latter course is especially desirable when the sizes of the various items approach or exceed the published sizes for the materials involved.

In using plates for machine construction, there are a few things the designer should keep in mind: up to and including 2 in. in thickness, plates are sheared and there is no charge for the cutting; above 2 in. they are flame cut, for which a charge is made according to the thickness; for 3-in. plates the charge is 45 cents per lineal foot—this increases with the thickness—and flame cutting on 12-in. plates costs $2.59 per lineal foot.

The universal mill rolls plates to exact width (within standard tolerances) but rolls the steel in one direction only. On this product the customer is charged for only two flame cuts if the material exceeds 2 in. in thickness. This product is obtainable in widths up to about 60 in.

Plate mills roll the steel in both directions and in very much wider widths. On this product the customer is charged for four cuts if the thickness exceeds 2 in. Both products take the same base price, 1.85 cents per lb.

Items which are not rectangular in form are called sketches. Regular sketches are those with four straight edges and take an extra of 20 cents per 100 lb.; irregular sketches are those with more than four straight edges and take an extra of 50 cents per 100 lb. Extras for sketches requiring re-entrant cutting are quoted on application.

Standard Variation and Tolerances

Variations and tolerances in thickness, width and length are all published and standardized. Variations from true flatness are also published and extras for special flattening are quoted on application. It is essential that the designer be familiar with these facts in order to use the cheapest possible material and at the same time to get the proper material for the purpose.

A Specific Example

Recently an inquiry was received for steel for the construction of a certain machine. It contained 29 items, which ranged from 24 in. square down to plates $^3/_4$ in. in thickness. On taking this up with the designer and informing him of the points previously explained, he resubmitted the inquiry and it contained twelve items. The prices on the various items run from $29.45 per gross ton up to 7.22 cents per lb. delivered, a difference of over $100.00 per ton, although it was all the same kind of steel. The high cost item was one piece $^3/_4$ in. thick, 4 in. wide and 22 ft. long. The reason for its extremely high price was that it was a bar instead of a plate and took a lump sum quantity differential of $12.00, the weight being only 224 lb. It was possible to change the design to eliminate this item. The fact that this high-priced item could be eliminated shows the flexibility of design with welded construction. The difference in the cost of the material in the two inquiries was $263.09 although the weight was increased 1453 lb. in the second inquiry.

Semi-Finished Material

There are many opportunities to use semi-finished material, such as billets, blooms or slabs, in machine construction, and the designer should know whether such material is suitable for the part. Billets have rounded corners, which might prevent them from being used for some purposes, but for many others they will serve very well and the finish will not be objectionable.

The surface of slabs is not suitable for machine construction unless the part is to be machined or is in an inconspicuous place, for slabs usually contain roll ragging marks. They are about $^3/_{16}$ in. high, $^3/_8$ in. wide and about 2 in. apart and, of course, can easily be planed off. Straightness in semi-finished material is something which must be considered if the pieces are in long lengths, for this material is primarily intended for

rerolling, which does not require it to be straight. Semi-finished material is low in price and, where it will serve the purpose, its use presents an opportunity for reducing the material cost.

Design of Mill Housing

A fine example of simplicity of design, the importance of using the proper material and the help the steel manufacturer can give the designer is the welded steel mill housing made by The E. W. Bliss Company for the American Sheet & Tin Plate Company. Some of the problems in the early stages of its design are of interest.

The problem was not simply to make a roll housing out of welded steel construction but to make one which would not cost more than a cast steel construction and still have qualities which would make it desirable. It was fairly well known what the cast steel housings would cost and, while the base price of plates was lower than the per pound price of steel castings, there was still the matter of scrap and welding to be considered. If the designer had attempted to reproduce a conventional housing in welded steel with all its irregularities of contour and section, the result would not have been acceptable nor would it have been practical from a cost standpoint.

When the link, Fig. 1, with an enclosed screwdown arrangement was decided upon, it was intended to make laminated links, using plates 2 in. in thickness, as shown in Fig. 2. This would have made a satisfactory mill housing, but mill practice and tolerances introduced such problems as machining the surfaces flat, price extras for width and flattening, and scrap allowance on discard material, which increased the final cost considerably beyond that of a cast steel housing.

It was then thought the links might be made from 1-in. plates, ten of which would be welded together as shown in Fig. 3 and the outside plates machined flat to take care of the "crown." Three of these packs were then to be put together and welded to make one housing. This would have saved a considerable amount of machining but did not solve the scrap question, as 1-in. plates were not desirable mill stock, nor could the customer take it in.

Two other alternatives were left—first, to build the links out of heavy forged slabs 8 in. thick, as shown in Fig. 4, in which case the customer would receive an allowance on the material cut from the window on the slab price basis, as it was suitable for rerolling. This amounted to more than 40 per cent of the entire weight of the forged slab. Also, the cost of flame cutting an 8-in. slab was more economical than to cut four 2-in. or eight 1-in. slabs. The second solution was to build up a link with the laminations running the opposite way, that is, at right angles to the line of rolling, as shown in Fig. 5. It was proposed to use universal mill plates, weld them together in the form of a link and shrink successive layers on a core until the required dimensions had been reached. This design eliminated all scrap.

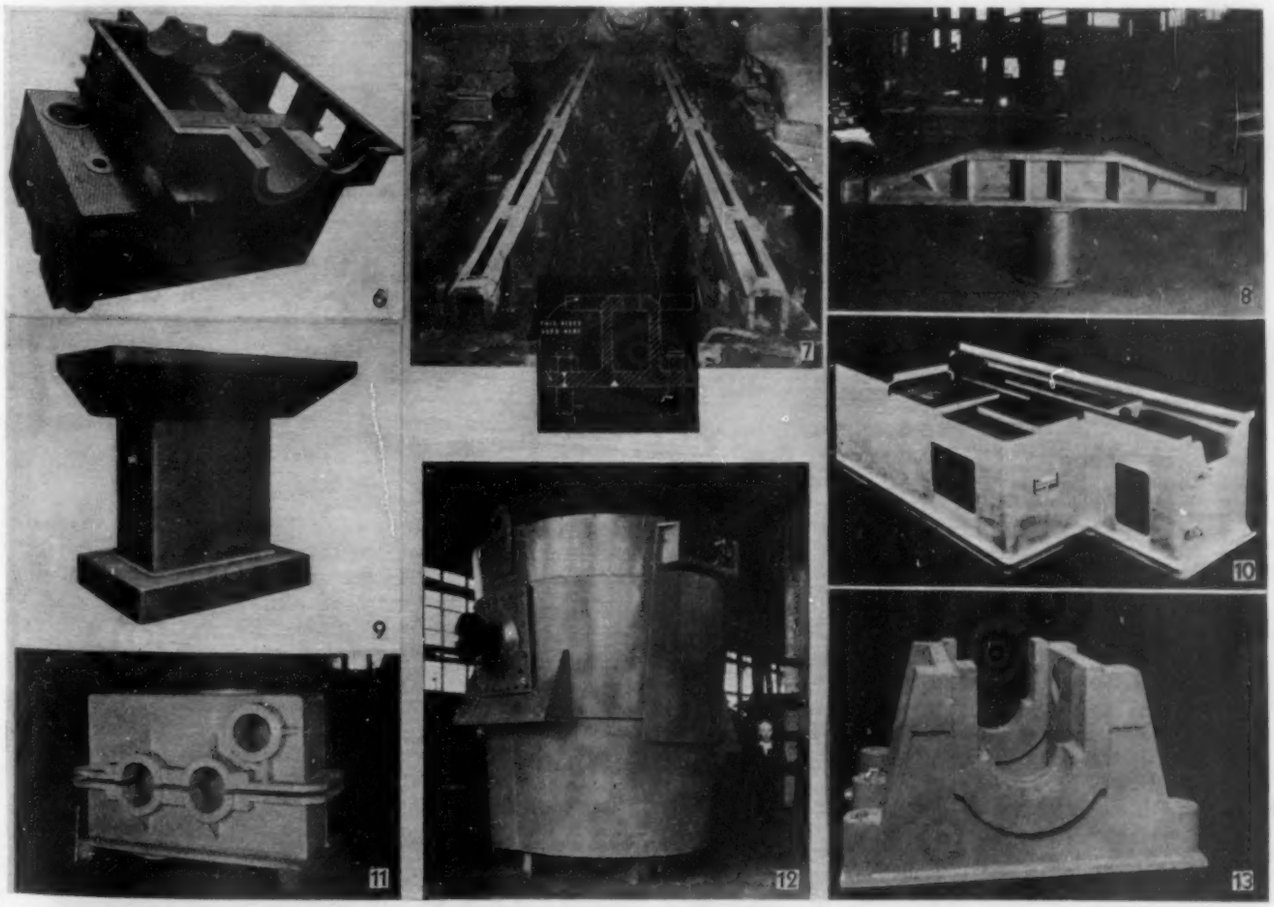

Fig. 6—Welded Gear Reduction Case Utilizing Structural Shapes to Good Advantage (W. E. & M. Co.). Fig. 7—Shoes for Mill Housing Made of Flame Cut and Welded Wide Flange Beams. Cost 32 Per Cent Less than Cast-Iron Shoes. Fig. 8—Use of a Rolled Section for This Bolster Reduced the Amount of Welding and Final Cost (Wellman). Fig. 9—Machine Stand Showing the Use of Bent Plates to Reduce Amount of Welding. Fig. 10—Machine Base, Effecting a Saving in Welding with a Decided Improvement in Appearance. Fig. 11—Welded Rolled Steel Gear Case. Fig. 12—Welded Rolled Steel Open-Hearth Ladle (Pollock). Fig. 13—Pinion Housing with Window Yoke of Cast Steel Welded in Place

It was decided, however, to make these links from forged steel slabs, Fig. 4, and the final figures showed this construction was competitive with a steel casting. This mill is a fine example of simplicity in design and of the importance of selecting the proper material for the construction.

Structural Shapes Economical to Use

The great variety of structural shapes now rolled by the various steel manufacturers are being used to advantage by designers of machinery, Fig. 6, but they are not used to the fullest extent. Perhaps the reason is because the designers have not yet learned to think in terms of rolled shapes as much as they should, or perhaps they are not familiar enough with the variety of sections which are available. In many welded structures, sections which can be obtained as a rolled shape are built up of welded plates. This means considerable flame cutting and welding, whereas many of the rolled sections can be purchased at about the same price per pound as the plate.

Generally speaking, a rolled section is the cheapest (Fig. 8), a formed section made by bending plates is next and the welded section is the highest in price. For example, a rolled channel is cheaper than one formed by bending a plate into a channel, and a bent or formed channel is cheaper than one welded from three plates. A rolled I-beam is also cheaper than one formed by welding plates together; however, if the I-beam is to be bent and will have considerable curvature, it would probably be cheaper to build it of welded plates rather than to use a rolled I-beam and attempt to form it. These are all simple things which the designer would naturally be expected to solve at a glance, but every-day examples may be seen of simple members welded up at a considerable cost, which can be procured as rolled sections.

Economy of Plate Bending

Another source of economy in the design of welded structures is the reduction of the amount of welding in a structure by bending or forming the plates. For example, a rectangular form obtained by welding four plates together, requires four separate welds, whereas the same results might easily have been obtained by bending the plates at the corners, which would require only two welds, or perhaps one, with a decided improvement in the appearance (see Fig. 9). This subject of forming plates is getting more attention and where the proper equipment is available it has resulted in considerable economy (see Fig. 10).

Combinations of Cast and Rolled Steel

One of the most effective economies is to combine steel castings with rolled steel. This subject should be given the consideration it deserves. There are many castings which could be made at a lower cost through such a combination and, on the other hand, many weldings where the cost could be reduced by making some parts of cast steel and welding them into the structure. An illustration is the all-welded rolled steel gear case, Fig. 11, in which the bearings have been flame cut from thick blocks of steel. There is little doubt that it would be cheaper to design most gear cases so that the bearings would be made of cast steel and welded in place similar to the construction shown in Fig. 13. It would require a very simple pattern and a cheap casting and the pattern would probably do for the bearings on both sides of the gear case.

Appearance of Structure

There is another source of economy in the design of welded construction which is more or less intangible in its nature, and before the full benefits can be derived from this source it will be necessary for us to change our ideas of the appearance of mechanical structures.

We become accustomed to seeing things built in a certain way and dimensions within a certain range seem to become part of the picture. If these dimensions are changed materially, we at once question the structure. As an example, on almost any large industrial machine some parts, like stiffening ribs, are made from $^1/_2$ in. to perhaps $1^1/_2$ in. in thickness, depending on the type and size of the structure. Instead of determining the thickness of these members through an analysis of the stresses to which the part would be subjected, they were simply made of such dimensions as would enable the metal to flow in the mold and insure a good casting. The additional weight involved is of little consequence as compared to the danger of losing the casting. In welded construction this excess weight is neither necessary nor economical and frequently such members may be materially reduced in size. Very likely a great deal of excess weight is going into some machines simply because the designer is still thinking in terms of cast steel rather than rolled steel, and also because the form and dimensions of many parts are determined by convention or appearance.

Perhaps if it were possible to calculate the thickness required for some of these members, the result would be a very weird looking machine. However, we readily adapt ourselves to changes in appearance, and in short time such changes will be acceptable.

There are many types of machines where light weight is a very essential factor, such as ladles (see Fig. 12), cranes, hot metal cars and other industrial railroad equipment. A reduction in weight means a saving in power, wear and tear and cost of supporting structures, etc. In this type of machinery it is important for the designer to take full advantage of the superior qualities of rolled steel and reduce weight wherever it is possible.

Skimping of weight is not advocated for, after all, a few pounds more or less is not of utmost importance, but the thought which should be kept in mind is that the designer is now using a different material and should take every advantage of its better qualities, its better adaptation for the purpose and its ease of fabrication; and if unnecessary weight can be saved, it is an economy which is well worth while.

Conclusion

Welding is "growing up"; the novelty of it has worn off and it must stand competitively against other forms of fabrication. We have become accustomed to seeing special machinery built by this process, where substantial savings are made through the elimination of patterns and other foundry expenses, but if we expect welded construction to invade the production field, that is, where machines are built in great number, economies in design must be studied and put into use to the fullest extent or welded construction will not be competitive. To just build a machine of welded steel construction is comparatively a simple job, but to design it in the most economical way is another question. It embraces many problems which will tax the engineer's ingenuity and a thorough knowledge of the material to be used, its method of manufacture and the cost of it in its various forms are absolutely essential. The steel manufacturer is not only willing but anxious to assist these engineers to the fullest extent.

Standard Connections for Welding

By VAN RENSSELAER P. SAXE†

THE writer has designed and constructed several all-welded steel frame structures including an eighteen story building, power houses, auditoriums, Armory Bldg., hospital school and training school buildings and numerous alterations in which welding was exclusively used.

In the design of this work we have been impressed with the fact that in all of the buildings we have designed and constructed that the welded designs were more economical than the riveted designs for the same steel frame. In our earlier work we issued to bidders two sets of plans, one showing riveted connections and the other showing the requirements for welded connections and designs. In all cases we found that the welded designs were producing the most economical steel figures and some of these buildings were built at a time when welding of structural steel frames was comparatively an unknown quantity with the average steel fabricating company. One of the first jobs had to be awarded to a steel mill company who furnished the steel cut to length delivered to the site. All of the actual welding that would usually be shop welding was done on the site of the job by a welding company which took the contract to do the welding fabrication, erect the steel and do the field welding required after erection of the steel. In spite of these difficulties, this contract, which had a number of large welded trusses and heavy girders, was finished at a cost of 11 per cent less than the same structural frame riveted, using the lowest steel fabrication rivet figure.

It is well to note that in all of our work done to date the owners of these welded buildings have secured reasonable savings through the use of welding as compared to riveting.

This brings us to the point of discussion as to the position of the designing engineer in doing work of this character and the fact that work of this character done by my office has cost us considerably more money to do than similar work done in riveted construction, and, while we were saving money for owners, we were actually doing work of a class which was costing us more money without being able to convince the owners that we should be paid slightly more for the welded work by taking some reasonable part of the owners' saving to compensate us for the additional work we were asked to do on welded jobs. Any one who has attempted such a solution with an owner knows without my saying what the answer was. They took the position, and I believe justly, that they employed engineers to design their buildings and, if a material was more economical to use than another, it was up to the engineer to recommend and use it; and it was the engineer's hard luck if he could not develop methods to make the design of that particular material as economical as the older more-used processes.

The extra cost to us of our earlier welded designs we attributed to the time spent in developing a thorough knowledge of the subject as applied to the job in hand, but after doing several jobs we still found that the costs were unreasonable. A careful analysis of all the work done finally indicated to us that our unusual costs were the result of the great amount of detail we had to show on plans to properly indicate the welding required for all of the different types of connections that would develop in a job, whereas in our riveted work due to the standards, developed by The American Institute of Steel Construction, we did not have to show but few detail connections, as we would cover all this work by simply calling for the Institute's standard beam and column connections for the varying size beams and columns.

With this information in hand, we felt that possibly we were foolish to continue to advocate the use of welding in building work even though it showed substantial savings, for it was costing us money to do work this way over and above what we could get for riveted designs which would satisfy the average owner and much better satisfy the average steel fabrication company, even though most of the better ones are now well equipped to do welded work in a very satisfactory manner.

† Consulting Civil Engineer.

Fig. 1—Welded Seat Angle Connections

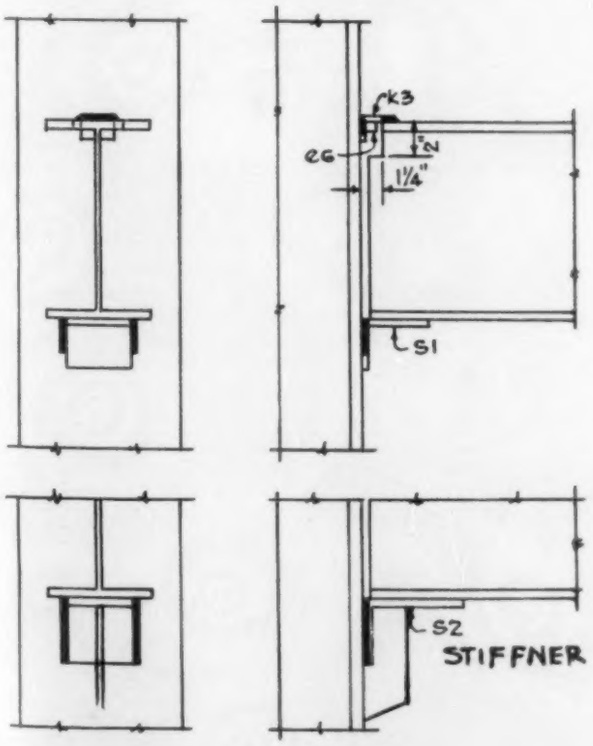

Fig. 2—Welded Seat Angle Connections

Incidentally, it seems to me that this condition, and perhaps some of the mystery some people try to throw around welded work, may account for the fact that it is not more widely used by engineers in their present-day designs, for most engineers do not have the time to dig into a new subject of this character when the old riveted method of doing work still is the accepted method.

There is the further fact of a lot of resistance to the use of welding by the steel fabricators who are not entirely sold on the idea because they have large investments in punching and riveting equipment which the simpler welding process will eventually eliminate from the picture.

We decided that if we wanted to give our owners the best that they could get for their money, we were obligated to continue to give them welded jobs and it was up to us as engineers to develop for the use of our office, methods which would help to keep our designing expenses within reasonable limits of the rivet construction; so to this end we began and developed a set of office standards showing the amount of weld required for all the types of steel beams in general use and connections to columns and splices, etc., for columns, following in general the same requirements for beam reactions as called for in the standard handbooks on riveted steel construction.

This, as one can understand, involved a large amount of detailed labor and research into all available welding information (which, incidentally, has many varying statements as to how to cover any particular condition to the extent that I believe any engineer not having experience with welding might find himself lost as to just the right thing to do).

Our completed standards were a great help to us on all designs made in our office after their completion and naturally reduced the cost of doing welded design work so much so that we were then on about the same basis of cost as in designing riveted work. As luck would have it, when the steel rolling mills last spring decided to cut the number of beams rolled and changed the web thickness of many beams, it meant that most of our standards had to be revised to make the welded connections correspond to these new beam sizes so that we are now getting them in shape again for the new conditions required by the new beams. In connection with these standards, we found that the welded steel erection seat we developed with The Schuster Engineering Co. gave the most practical method of fastening unwelded beams during construction as it does away with all hole punching in beams for the field connections and is the most economical method we have used. These people charge a small royalty of one dollar per ton of steel frame in which these seats are used, which added to the small cost of each individual seat which develops less cost than the earlier methods we used. Our drawings show these seats, but seat angles can be used to produce the same results by use of clips or holes punched in the beams to hold them in place during erection.

Our experience with these standards indicates that the Society could arrange for one of its standing committees to make up a set of standards for welded connections following along the lines of the same standard values for similar connections in riveted work as indicated and used in the structural steel handbook.

As all structural steel work done in cities is subject to Building Codes and approval in design and erection by Building Inspectors and their engineers, I have had in connection with my work under these men many discussions about welding, especially in those cities where welding is not approved except for special work and by special ordinance for the work proposed. From my talks

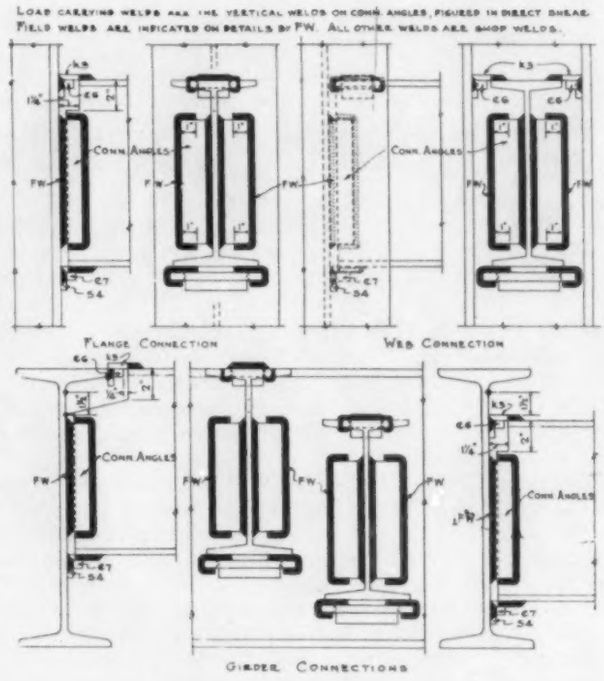
LOAD CARRYING WELDS ARE THE VERTICAL WELDS ON CONN ANGLES, FIGURED IN DIRECT SHEAR.
FIELD WELDS ARE INDICATED ON DETAILS BY FW. ALL OTHER WELDS ARE SHOP WELDS.
CONN ANGLES
FW
FLANGE CONNECTION
WEB CONNECTION
GIRDER CONNECTIONS

Fig. 3—Welded Beam Connections

with these Building Inspectors I have found a feeling of opposition to welding occasioned generally because of lack of any authoritative standard information.

While these building engineers as a rule understand and appreciate the merits of structural welding still they express opposition because of this lack of detailed standard information which would be of much help to them in checking plans for welded building construction. They also feel the fact that their city job inspectors have insufficient data to properly inspect work under construction. These building engineers feel that if there was available standard connection data that they could have this as a basis for instructing their men as to the amounts of weld that they could be expected to look for on beam connections.

I have often been questioned by these engineers as to why it is not possible to develop a set of standards from which all engineers would have a guide in the design, checking and inspection of structural welded work in much the same manner as on riveted work. They do not see why this cannot be done, and from our experience in getting up our own tables of standards I do not see why it cannot be done so that all engineers will have a standard basis from which to figure welded work.

Such a set of standards with the authority of recommendation by the Society back of them would be of great value and assistance to any structural engineer desiring to do welded work, as such standards would save him a great amount of work in his design and it would give all steel fabricators and steel detailers a definite type of connection to use for all of the different beam sizes. I am confident that such a published set of connection standards, welded plate girders and trusses, assembled by this committee, will not only greatly increase the use of welding in steel structures but also, if handled by the Society and sold for a reasonable sum, could be made a source of income to the Society.

As a result of our experience, there are certain definite types of connections which are preferred in building frames, and, as this is the greatest possible outlet for welding materials and information, I would suggest that

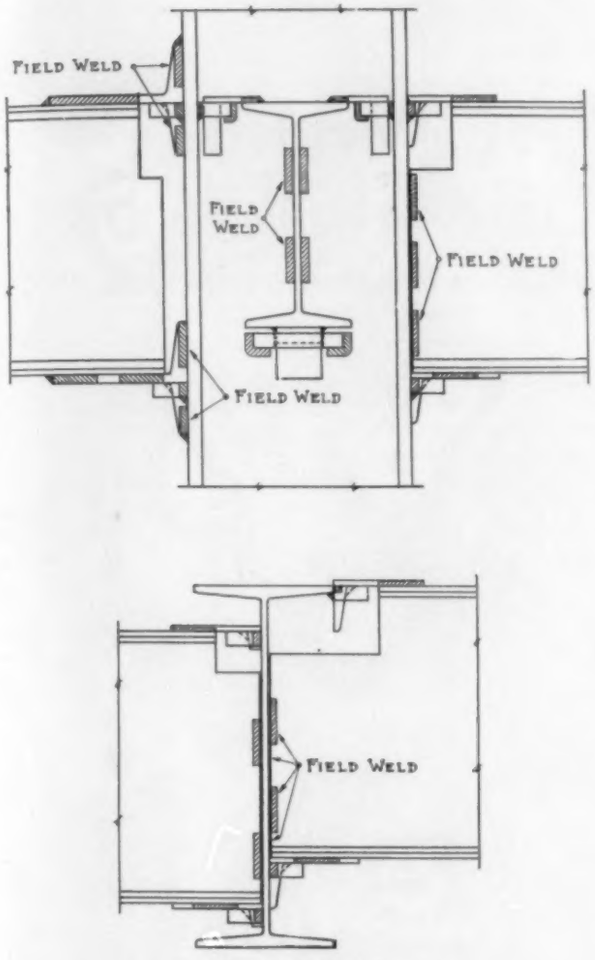

Fig. 4—Welded Web Connections

information developed on the following types for general use would be possibly the first step in developing standards.

Figure 1 illustrates the simplest form of seat angle welded to a column or beam web for the support of ordinary beam or girders. This type cannot be used very successfully in any but the lower type of building due to the fact that it does not develop sufficient erection rigidness during construction unless a top clip angle is welded to the beam (Fig. 2) during the process of erection and in the heavier loads where stiffeners are required under the seat angles, but there is usually objection to these stiffeners because they project beyond plaster lines and make a break in the finished surface, which must be covered with fireproof material to secure proper insurance conditions. However, these seats serve a useful purpose and standards for their use should be developed.

Figure 3 indicates the type of connection most generally used in steel construction and best adapted and accepted by engineers and steel fabricators for erection purposes. This type of connection does not have any projecting parts below the beam and is readily adapted for beam connections to beams and beam connections to columns. In a welded design this type of connection uses materially less steel than the same load requirement in rivets and should be thoroughly developed. The use of this connection by welding saves cost over a riveted design.

Figure 4, showing a direct welded web connection between beam to beam or beam to column, is the most economical and should be the final development in welded connections. The amount saved in weight of connection angles as in Fig. 3 and the saving of lines of welding required more than offset the cost of having the beams cut to exact length where this type of connection is used.

The writer has been reluctant to use this type except under extreme conditions due to the grades in welding rod procurable in past years. However, we believe that now with the great improvement in rod material with its greater ductility that it will be possible to demonstrate by test that this type of connection can be used safely even when beams are figured as simply supported by placing weld material of sufficient quantity to take the stretch due to initial deflection of the beam after it has been loaded from the unloaded condition it is usually in at the time the field welding is done. Under most loaded conditions the weld can be placed so it is not materially affected by the deflection conditions. A considerable amount of information could be developed on the connection by a comparatively few tests of a varying number of different depth beams, and the type of connection should be included in any list of standards as in our opinion it is the most direct and economical type for welded work.

There are many other detailed connections such as splice plates on columns, base plate connections to columns, typical truss panel connections, theory, summary Welding Society recommendations on welding, inspection, etc., all of which could be incorporated in a book of this character, which would be of great service to all branches of the welding industry.

It would seem that now is a good time to start such a work as many members of the committees are not so busy that it would be a burden to them to help in the preparation of such vital and necessary information, if the welding industry is to take the place it deserves in the structural field.

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Corrosion-Fatigue Study of Welded 18:8 Stainless Steel*

By WILBER E. HARVEY,† ARTHUR J. CIASTKEWICZ†† and F. JEROME WHITNEY, JR.†††

Corrosion-Fatigue

ABOUT ten years ago Dr. D. J. McAdam, Jr., discovered that cooling water applied to the surface of a fatigue specimen under test acted as a chemical agent and not as the expected thermal agent which would aid in keeping the specimens from overheating during testing. With water directed on the surface of a fatigue specimen during testing the specimens developed a very premature failure. This discovery has led to one of the most interesting fields of research unearthed during this century.

The dangers of fatigue were already well known and feared by designing engineers. Starting with the studies of Wohler about 1870, considerable attention was directed toward the study of repeated stresses and the solution of their effect upon materials, both ferrous and nonferrous. The era of the automobile and airplane which followed in the early part of the twentieth century stimulated many very complete studies upon the effects of fatiguing stresses upon dynamic members of various structures. Today, the problem of repeated stresses is one which has been fairly well conquered by modern engineers. It is well known that the fatigue limit in alternating flexure stresses is about 35 to 50% of the static tensile strength for wrought ferrous metals. The designer now aims to overcome the dangers of stress raisers which are so fatal in parts subjected to dynamic stresses and also to compensate for the lower allowable working stress.

With the conquering of one bane of the metal, users approach a still even greater menace. The effects of corrosion are so well known to engineers that little could be added to the subject in this treatise. With the thoughts in mind of the problems of fatigue and also the problems presented by corrosion it is reasonable to expect that the combined effects of the two would be far more deleterious than by either factor by itself.

Picture for a second an alloy steel with a static tensile strength of about 250,000 lb. per sq. in. which would have a fatigue limit in air of about 110,000 lb. per sq. in. If this fatiguing action were accompanied simultaneously by a corrosion effect in ordinary carbonate water the fatigue limit would be lowered to a value somewhere between 10,000 and 25,000 lb. per sq. in. Instead of the 35 to 50% of the static tensile strength to use as a design value the engineer is forced to design with a corrosion-fatigue limit which is approximately 4 to 10% of the static tensile strength of the material. There is little wonder that such a dangerous problem has attracted the attention of many investigators in the past five or six years. It is a problem which will demand more and more investigation and study as the years pass.

At the present moment little is known about the actions of this dangerous combination of fatiguing stresses and corrosion. McAdam has already indicated that there is no steel, carbon or alloy other than the stainless types, which has a higher corrosion-fatigue limit than 25,000 lb. per sq. in. The mechanism of this combination of dangerous actions is not at all well understood, although it is quite accepted that the problem is, in general, one of an electrochemical nature. It is known that the solution tendency of a material subjected to corrosion-fatigue conditions is not measured by the electrolytic solution pressure of the metal itself but that it is measured by an electrolytic solution pressure which is enhanced by the fatiguing stresses. Accurate measurement of this enhanced electrolytic solution pressure is impossible without very elaborate laboratory equipment and quite a lengthy study. It is possible that even with this study that the results obtained would mean but little although they would contribute to the amount of fun-

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* Paper presented at Fall Meeting, A. W. S., October 1–5, 1934. Contribution to the Fundamental Research Committee, A. B. W.

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††† Formerly graduate student, Dept. of Met. Eng., Lehigh University.

Fig. 1—Testing Machine

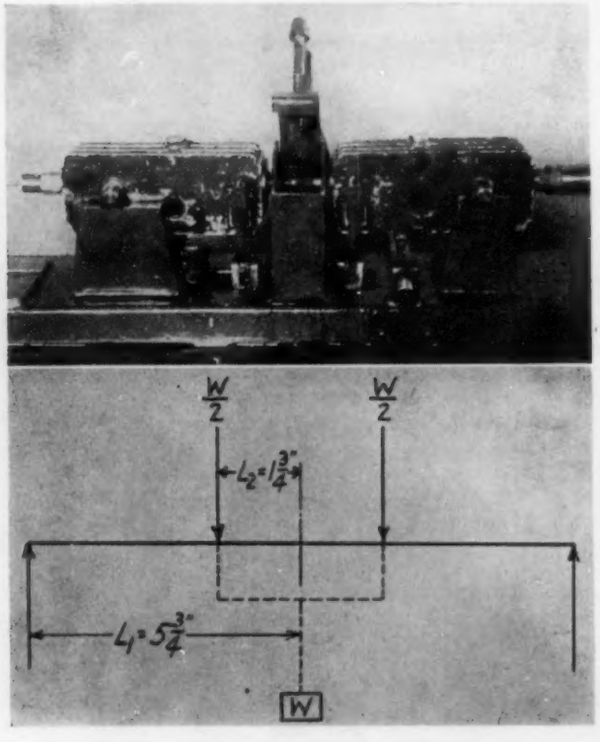

Fig. 2—Loading the Specimen

damental knowledge available. However, it has been proved that the corrosion-fatigue limit is a definite function of the corrosion resistance of the material itself which indicates that all efforts to combat the problem of the combined effects of corrosion and fatigue must necessarily be directed upon minimizing the effects of corrosion. Considerable work has been done toward minimizing or excluding corrosion from the variables of the problem thus reducing the problem to as nearly an approach to air fatigue as possible. Experiments using inhibitors in the corroding medium and also experiments using plated metals of various types have shown gratifying results in raising the corrosion-fatigue limit of the material studied.

Corrosion-Fatigue Studies of Welds

About three years ago the discussion of corrosion-fatigue studies of welds aroused considerable attention. In a weld in which metal is deposited for the joining of sections there is almost invariably a potential difference existing between the weld metal and the parent metal. A potential is a measure of the electrolytic solution pressure of any metal. Another definition of potential would be the measure of the tendency of the metal to dissolve or enter solution. With dissimilar metals present as in the case of a fusion weld there must exist a difference in potential since both the deposited metal and the parent metal possess their own electrolytic potential or desire to enter solution. With a difference of potential existing within a material an electrogalvanic cell is created. The presence of a galvanic cell immediately enhances the dangers of corrosion in the material. The part of the material which is acting as the anode of the galvanic cell dissolves with the accompanying protection of the cathodic or lower potential part of the material. Thus, in most welds ideal conditions are present for severe stressless corrosion—then what results might be expected if this ideal condition for stressless corrosion were supplemented by fatiguing stresses since it is known that the repeated stresses will increase the electropotential of any material?

It was decided to study the corrosion-fatigue properties of welded materials at Lehigh University. The study was to include a series of plain-carbon steels welded by different processes and also a series of stainless steels also welded by various methods. The problem was divided into two parts—first, the study of the boiler plate material and second, the study of the stainless steel.

The results of the first half of the investigation were presented to the AMERICAN WELDING SOCIETY at their annual meeting at Buffalo in 1932. The information gleaned from the tests of the boiler plate material were of sufficient interest to warrant continuing the second part of the study upon stainless steel.

Procedure for Investigation

It was decided to study an austenitic stainless steel of the 18% chromium : 8% nickel type. This type of stainless steel has become very popular in the past five or six years and is one which is used in many industries where complete corrosion resistance is necessary.

A big problem for consideration in the study of the stainless steel was the type of corroding medium to be used during the tests. Almost every industry finds stainless steel exposed to a different type of corroding medium, each corroding agent of which will cause a different rate of attack upon the stainless steel.

Considerable correspondence ensued with both makers and users of stainless steel. Quite naturally the choice of various concerns differed considerably. Among the corroding media suggested were lactic acid, some material to simulate beer in corrosive action on metals, the copper sulphate solution used by many companies as a measure of corrosion resistance of 18:8 and others. It was quite impossible to use some of these reagents in the laboratory due to various restrictions among which possibly the greatest was the lack of funds which would be necessary for the application of some of the solutions. After considerable discussion it was decided that perhaps the best corroding medium to use for early tests was plain water. Water was chosen for several reasons among which are the following:

(*a*) Water is the usual corrosive agent encountered in industry. There is possibly a greater tonnage of 18:8 steel exposed to water conditions than any other attacking reagent.

(*b*) The use of water eliminated the necessity of installing a pumping system for the return flow of the used corroding medium such as would be necessary in the case of lactic acid and other corroding media.

(*c*) The results obtained would be comparable to the results reported upon plain-carbon steels since water was the corroding medium used throughout the earlier half of the test program.

It was decided again to send steel to various commercial welding companies soliciting their aid in the securing of good test welds. Each company was requested to do the welding in any manner considered by them to be the method of securing the best welds possible. The welding companies were in each case asked to heat treat the welded material in any manner which was considered best in their opinion to secure maximum corrosion resistance in their welded specimens. At no time was any direction given to the welder as to the procedure of the welding or the heat treatment of the welded material. In this way it was hoped to secure the best type of welds possible.

Equipment

The R. R. Moore rotating beam type fatigue machine was used in all of the tests. A few minor changes were made to the machine, but only such as were necessary for the application of the water to the specimen. A photograph of the machine is shown in Fig. 1. The speed of the machine was 1750 r.p.m.

The water used as a corroding medium was Bethlehem city tap water which is substantially a carbonate water. The water was applied directly upon the plane of maximum stress which was in every case the location of the weld. A constant stream of water was applied and the temperature of the water was that of the surrounding atmosphere or about 75° F.

All of the welded specimens were given a similar polish. The machining tool marks were removed by emery papers and the final polish was longitudinal wherein no circumferential scratches from previous polishings were visible.

Calculation of Stresses

A standard beam type specimen is used in this testing work. The beam is uniformly loaded at two points equidistant from the plane of maximum stress. The stresses formed are alternating flexures. A cross section of the weights and loading for this particular testing machine are shown in Fig. 2.

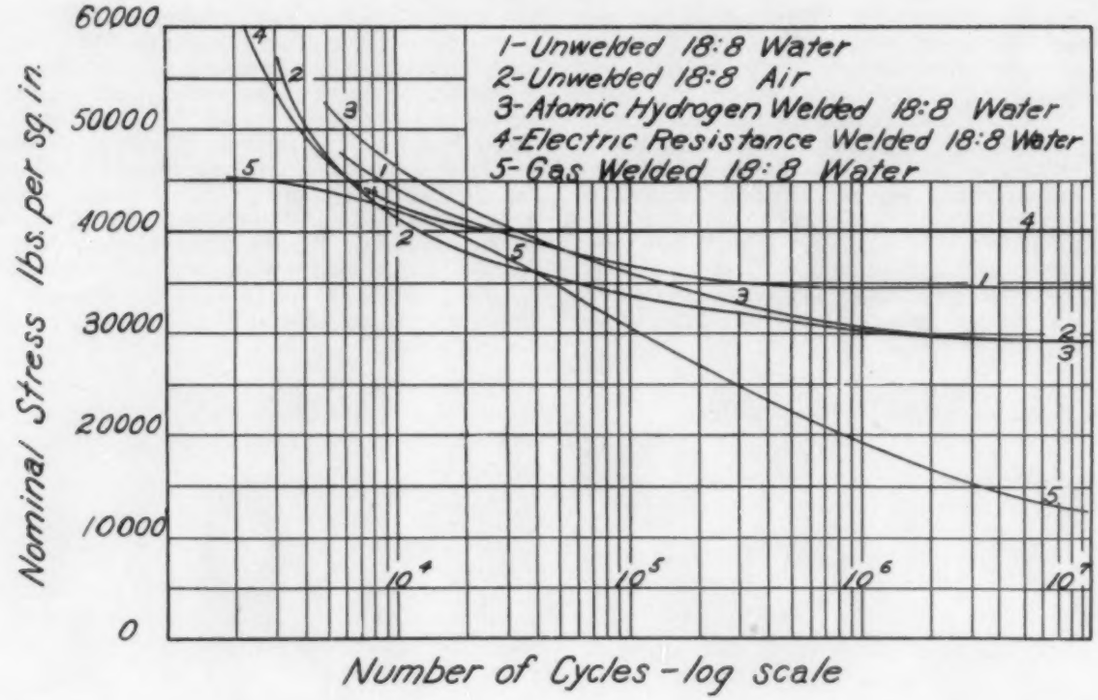

Fig. 3

$$S = \frac{Mc}{I}$$

$$c = {}^1/_2 d$$

$$I = {}^1/_{64}\pi d^4$$

$$S = \frac{\frac{W}{2}(L_1 - L_2)}{0.0982\, d^3}$$

For R. R. Moore standard fatigue specimen of 0.3 in. cross section

$$S = \frac{4W}{0.0053}$$

$$W = 0.001325\, S$$

Material

The stainless steel used was the Rezistal KA-2 type of which the following is an analysis:

Carbon	0.07%
Manganese	0.50%
Phosphorus	0.014%
Sulphur	0.016%
Silicon	0.37%
Nickel	9.61%
Chromium	17.36%

It was desired to test four types of welding processes: electric arc, gas, atomic hydrogen and electric resistance. However, it was impossible to secure in the time available electric arc welds of sufficient good quality for use in test work. Several sets of arc-welded specimens were made but none were of such quality as to warrant their use in fatigue-testing work. Insufficient time caused the necessity of dropping arc-welded material from the testing program. It is possible that at some future time the results of these tests will be published. By the omission of arc-welded tests it is not wished to infer that arc welds which would be satisfactory for fatigue study cannot be made but simply that the available arc welds were unfit for study.

(*a*) Atomic Hydrogen Welded 18:8

The filler rod used in the atomic hydrogen process was a KA-2 composition which is similar to the base metal. The chemical analysis of the filler rods falls within the following limits:

Carbon	0.07% max.
Manganese	0.40 to 0.65%
Phosphorus	0.035% max.
Sulphur	0.035% max.
Silicon	0.30 to 0.75%
Nickel	8.0 to 9.50%
Chromium	17.0 to 19.0%

The average used throughout the welding was 45 amp. and the filler rod was an ${}^1/_8$-in. rod.

The welded specimens were heat treated by quenching in oil from 950° C. (1750° F.) after welding.

The welds in all cases seemed to be perfectly sound and free from welding defects.

(*b*) Gas Welded 18:8

The gas-welded specimens were welded using KA-2 filler rod. The welds were of the V type. After welding the specimens were heat treated to 2000 to 2059° F. and cooled in air. The samples were sand blasted and dipped in nitric acid after welding.

There was considerable porosity in some of the gas-welded specimens and some had to be discarded as being unfit for fatigue testing. It is possible that some of the specimens tested had very small blowholes which lowered their fatigue resistance but in none of the broken specimens was any trace of porosity noted.

(*c*) Electric Resistance Welded 18:8

The electric resistance-welded specimens were of the flash weld variety. It was impossible for the welder

to heat treat the specimens and it was necessary for them to be heat treated in the laboratories at Lehigh University. They were heated to 2025° F. and quenched in water.

The welds all appeared to be very sound and free from welding defects.

Data and Results

The results of the tests are shown in the following tables. It was considered unnecessary to publish a curve for each set of results. A composite set of fatigue curves is shown in Fig. 3. The composite curves were plotted from the values shown in the tables which makes it possible to find the absolute life of the welded material for the stress at which it was tested.

Unwelded 18:8—Air

Stress, Lb. per Sq. In.	Cycles
50,000	3,900
40,000	11,300
35,000	74,300
30,000	4,464,500
27,000	10,000,000 removed unfailed

Unwelded 18:8—Water

Stress, Lb. per Sq. In.	Cycles
45,000	8,000
35,000	2,581,000
35,000	10,000,000 removed unfailed
30,000	10,000,000 " "
25,000	10,000,000 " "

Atomic Hydrogen Welded 18:8—Water

Stress, Lb. per Sq. In.	Cycles
50,000	6,100
40,000	31,400
35,000	187,900
30,000	6,680,000
25,000	10,000,000 removed unfailed

Gas Welded 18:8—Water

Stress, Lb. per Sq. In.	Cycles
45,000	2,100
40,000	29,000
35,000	29,900
25,000	180,000
20,000	951,300
17,000	3,942,000
14,000	5,184,000

No remaining sound specimens, so the true 10,000,000 limit could not be secured.

Electric Resistance Welded 18:8—Water

Stress, Lb. per Sq. In.	Cycles
60,000	2,200
50,000	4,000
45,000	5,400
40,000	10,000,000 removed unfailed
35,000	10,000,000 removed unfailed

From the above tables the fatigue limit in air of the unwelded 18:8 material is about 28,000 to 29,000 lb. per sq. in. while the corrosion-fatigue limit of the same unwelded material is about 34,000 lb. per sq. in. The corrosion-fatigue limit of the resistance welded 18:8 is about 40,000 lb. per sq. in. while the corrosion-fatigue limit of the atomic hydrogen welded 18:8 is 29,000 lb. per sq. in. The true corrosion-fatigue limit of the gas welded 18:8 could not be determined due to an insufficient number of specimens but it would be about 10,000 to 12,000 lb. per sq. in.

Discussion of Results

There are several items of unusual interest furnished by the results obtained in the tests. It will be noticed that the corrosion-fatigue limit of the unwelded 18:8 material is about 5000 lb. per sq. in. higher than the fatigue limit in air of the unwelded material. This phenomenon is quite unusual among ferrous alloys although it is known to be true of some non-ferrous alloys. It is well known, however, that a high chromium steel will heat very rapidly when stress is applied to it due to in-

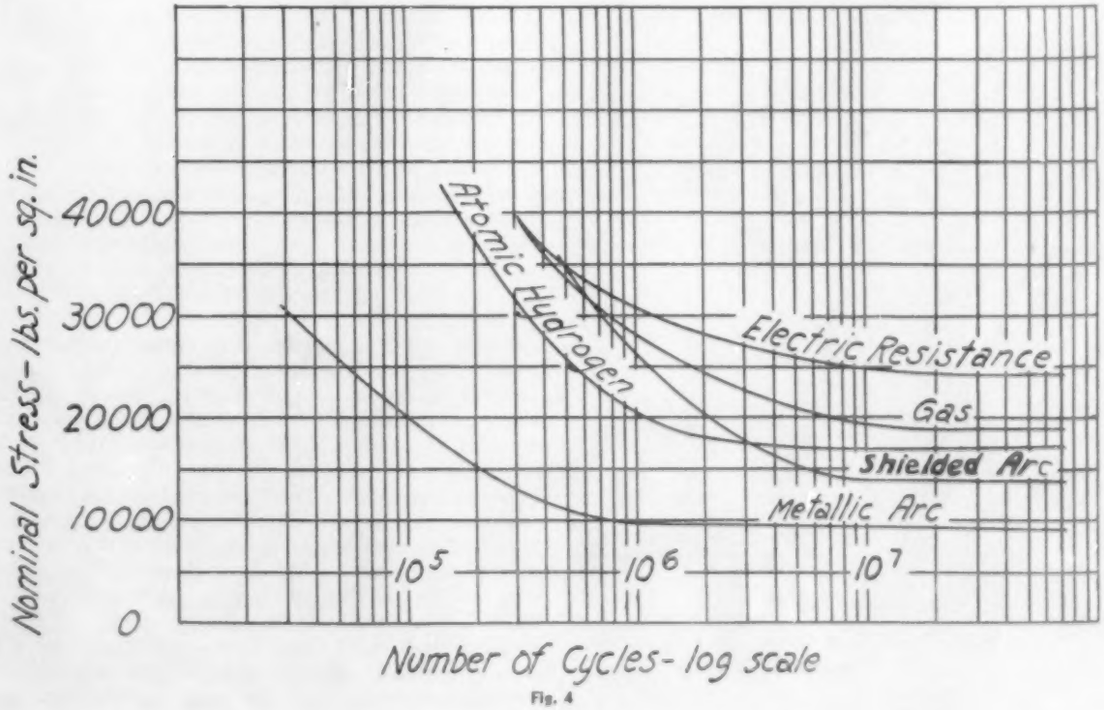

Fig. 4

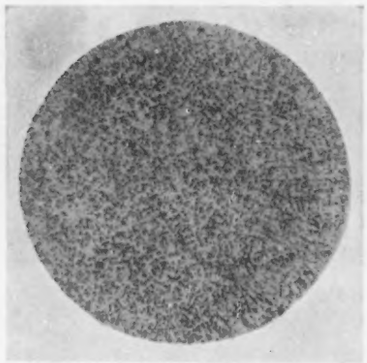

Fig. 5—Weld Metal in Atomic Hydrogen Weld. Etched in HCl, HNO_3, Glycerine. Magnified 100 Diameters

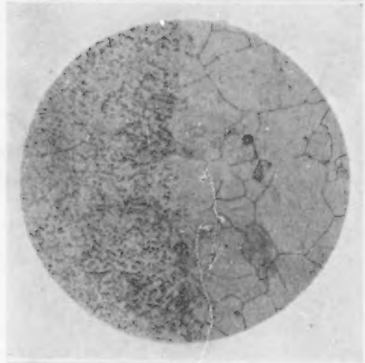

Fig. 6—Junction of Weld Metal and Parent Metal in Atomic Hydrogen Weld. Etched in HCl, HNO_3, Glycerine. Magnified 100 Diameters

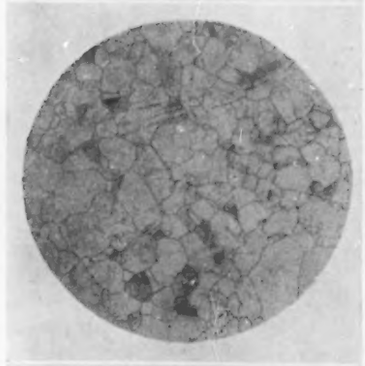

Fig. 7—Parent Metal in Atomic Hydrogen Weld. Etched in HCl, HNO_3, Glycerine. Magnified 100 Diameters

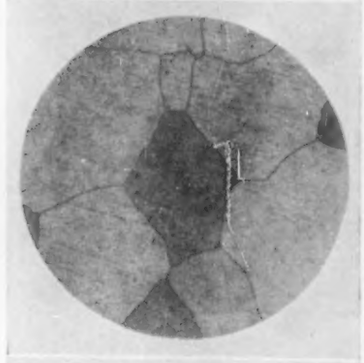

Fig. 8—Weld Metal in Gas Weld. Etched in Curran's Solu- Magnified 100 Diameters

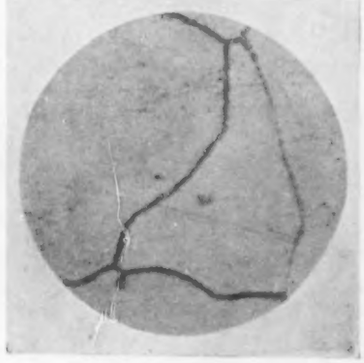

Fig. 9—Weld Metal in Gas Weld. Etched in Curran's Solution. Magnified 500 Diameters

ternal friction. The author has seen many high chromium steels turn dark and become even dull red during fatigue testing at high stresses. The application of water to the surface of a stainless steel material acts as a thermal agent rather than a chemical agent as in the case of a plain-carbon steel and as a result the stainless steel was kept cool with the resulting rise in the corrosion-fatigue limit of the material. It appears as if the fatigue limit in air and the corrosion-fatigue limit of 18:8 are similar values if the steel is kept cool during the testing of the specimens in air providing the cooling medium has no chemical effect upon the steel as is the case of water upon austenitic steel.

Another point of extreme interest is the high corrosion-fatigue limit obtained for the resistance welded material, it being about 6000 lb. per sq. in. higher than the corrosion-fatigue limit of the unwelded material and about 11,000 lb. per sq. in. higher than the fatigue limit of the unwelded material in air. This phenomenon is very peculiar but there is little doubt in the authors' minds that the results are safe. Figure 4 is a composite curve of the results obtained with the welded plain carbon or boiler plate material published two years ago. The corrosion-fatigue limit of the boiler plate steel was about 16,000 to 20,000 lb. per sq. in. The corrosion-fatigue limit of the electric resistance welded boiler plate material was about 24,000 lb. per sq. in. This result is similar in effect to the results obtained with the electric resistance-welded stainless steel.

The authors have developed an explanation for this phenomenon which seems to be in their opinion a correct solution. The union of the metals in the electric welded specimens is directly in the critical section of the specimen. This critical section must be cathodic with respect to the stainless steel itself since none of the specimens broke in the welded area. In other words there is a higher potential in the stainless steel itself to corrode than in the actual critical section where the weld exists. This assumption means that the higher potential metal exists in a section which has a larger area than the area existing in the critical section due, of course, to the tapered design of the fatigue specimen.

The stresses applied to the specimens are nominal values which exist only as actual stresses of that value at one locus, that of the least area, which is in the weld. The actual stress progressing from the weld to the ends of the specimens decreases since the area is constantly increasing. Therefore, with a nominal stress of 40,000 lb. per sq. in. on the welded area the actual stress in the anodic material which is slightly removed from the weld section must be somewhat lower. The failure or non-failure of an electric resistance-welded specimen depends upon the maximum actual stress in the anodic metal. If the actual stress in the anodic metal exceeds the corrosion-fatigue limit of the stainless steel which is in this case the anodic material, then failure will occur in this area where the actual stress has exceeded the corrosion-fatigue limit of the anodic material. The actual stress in the anodic material, however, will exist when there is a considerably higher nominal stress on the area of least cross section at the weld. So when the nominal corrosion-fatigue limit of the electric resistance-welded material is determined to be 40,000 lb. per sq. in., it simply means that the anodic part of the welded specimen is at the corrosion-fatigue limit of the stainless steel which is 34,000 lb. per sq. in. as determined by the unwelded specimens. If the design of the fatigue specimen had been such that there would have been a considerable length of constant area which included both the cathodic weld area and the anodic adjacent areas, then

the corrosion-fatigue values obtained would have been 34,000 lb. per sq. in. but failure would always have occurred at some point other than directly in the weld union.

The microstructure of the electric resistance-welded material revealed a completely solid solution or austenitic structure. There was no indication of precipitated carbides. There were a few inclusions in the junction of the metals.

The atomic hydrogen-welded specimens showed a corrosion-fatigue value of about 28,000 to 29,000 lb. per sq. in. This value is about 5000 lb. per sq. in. lower than the corrosion-fatigue limit of the unwelded material. It was noticed that all of the failures occurred in the weld or at the junction of the deposited metal and parent metal. Some of the broken specimens were placed near a compass and it was found that the weld section would attract one of the poles of the magnet. This attraction of a magnetic pole indicated that there was a precipitation of carbide in the weld metal since austenitic stainless steel is non-magnetic.

Figures 5 and 6 illustrate the microstructure of the weld metal and the junction of the weld metal and the parent metal. It will be seen that the weld metal is entirely composed of precipitated carbide. This weld metal will have a potential which is higher than the potential of the stainless steel and failure will occur in the weld metal. Hence the corrosion-fatigue limit of the weld metal will be lower than that of the unwelded material. Figure 7 illustrates the microstructure of the 18:8 steel itself in the atomic hydrogen-welded specimen.

The precipitation of the carbide in the weld metal indicates that the heat treatment given the atomic hydrogen welds was not such that the weld metal possessed a maximum corrosion resistance.

The gas-welded specimens showed an unusually low corrosion-fatigue limit—about 10,000 to 12,000 lb. per sq. in. This very low value was due to two causes. Three of the original ten specimens welded for fatigue specimens had to be discarded because of blowholes and porosity. While the other seven specimens revealed no visible blowholes, it is possible that there existed smaller welding defects which would contribute a damaging effect during test. It is very possible that some of the lowering of the corrosion-fatigue limit was due to this cause since the specimens did not break consistently at values which were predicted for them.

Some of the broken sections were placed near a pole of a magnet and the pole of the magnet was slightly attracted. The attraction was not nearly as strong as in the case of the atomic hydrogen-welded specimens but there was a perceptible attraction. The microstructure of the gas-welded specimens was then studied. The weld metal at magnifications of 100 diam. appeared to be completely austenitic. On further study the grain boundaries appeared to be rather heavy. Examination at 500 diam. showed the heavy grain boundaries not to be simply grain boundaries but groups of very finely divided carbides which had been precipitated in the grain boundaries. Figures 8 and 9 illustrate these grain boundary carbides at magnifications of 100 and 500 diam., respectively. This intergranular precipitation of carbides is a particularly dangerous condition since corrosion will start at the carbide areas and the result will be an intercrystalline corrosion, eating out the grain boundaries of the material leaving a sort of sponge-like metal which possesses little strength.

The heat treating temperature of 2000 to 2050° F. was possibly the best temperature possible for the heat treatment but one of two possibilities must have existed. Either the carbide precipitated by welding was not redissolved during the heat treatment or if solution had occurred, the carbide was reprecipitated upon cooling from the heat treating temperature.

If the gas welds had been of a better quality and the heat treatment retained the carbides in solution, the corrosion-fatigue value of the gas-welded specimens would have been considerably higher.

Conclusions

The study of the corrosion-fatigue properties of welded metals seems to divide itself into two classes:

1. The class in which the weld metal is anodic to the parent metal or metal being welded. In this condition the failure will always occur in the weld metal. Accordingly, the corrosion-fatigue limit of a welded section of this type will always be lower than the corrosion-fatigue limit of the parent metal. This class is the more common of the two and seems predominant in any welding process where there is deposition of weld metal.
2. The second class and the less common of the two is the case where the weld metal or welded section is cathodic to the parent metal or metal being welded. Under these conditions the failure will not fail in the weld but in the adjacent material. Hence the maximum actual corrosion-fatigue limit possible is the corrosion-fatigue limit of the parent metal since it is the anodic part of the welded section. In a tapered fatigue specimen such as the R. R. Moore type, while the actual corrosion-fatigue value will be that of the parent metal, the nominal corrosion-fatigue limit or the stress at the minimum area in the weld section will be somewhat higher. The electric-resistance type of welding seems to be the only welding process which falls into this second class.

It would appear that, if a welded section is subjected to the simultaneous action of repeated stresses and corrosion, an electric resistance weld should be used for the maximum resistance.

A comparison of Figs. 3 and 4 indicates that while welded stainless steels have higher corrosion-fatigue values than welded boiler plate, much more care must be applied to the heat treatment of the stainless steels since no heat treatment was used on any of the boiler plate materials. If the heat treatment of the welded stainless steels is such that will allow carbides to precipitate in the grain boundaries then the stainless steel will have less corrosion-fatigue resistance than a carbon steel. However, with proper heat treatment to insure maximum corrosion resistance, the stainless steel will always offer more protection against the combined action of repeated stresses and corrosion.

Acknowledgments

Among the firms to whom much credit must be given for assistance in the completion of this research are:

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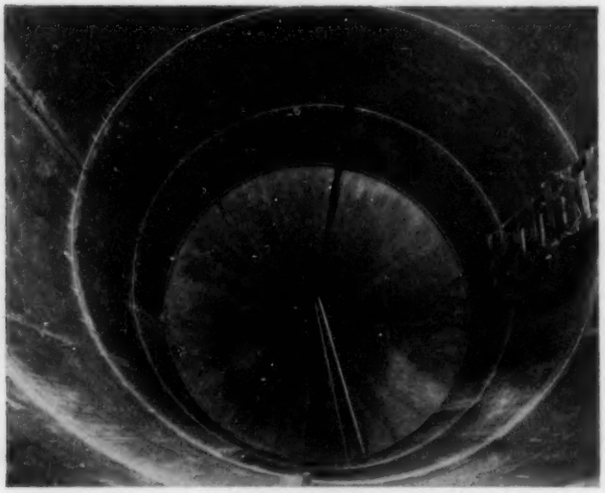
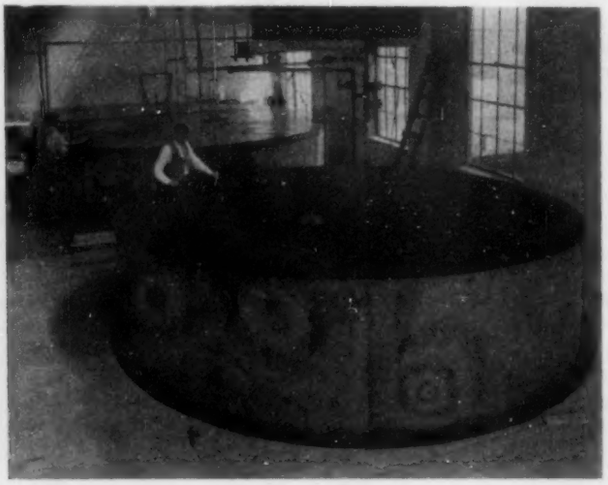
Encouragement in the research was offered by Professors Bradley Stoughton and Inge Lyse, both of Lehigh University. Much gratitude is due laboratory assistants too numerous to mention here.





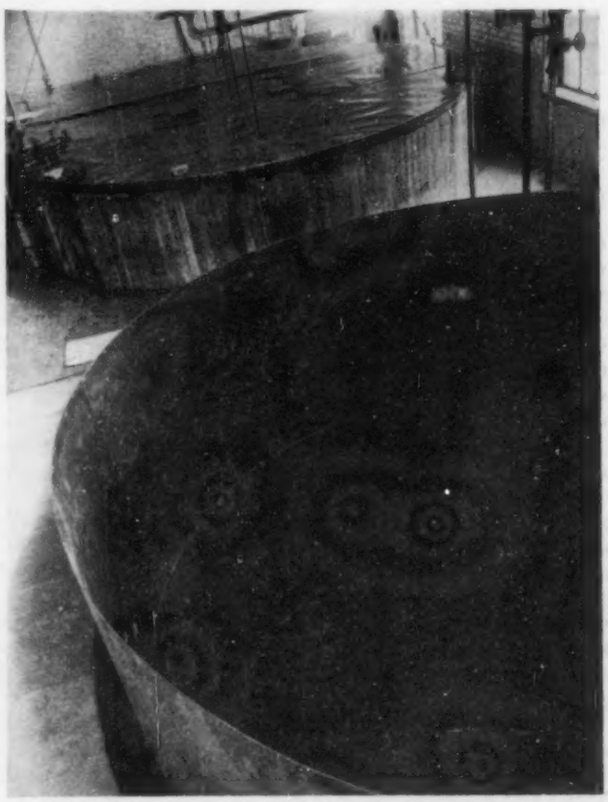
Large Soap Boiling Kettle Fabricated from Nickel-Clad Steel

By GEORGE A. CARDWELL †

SOUTHWEST Welding and Manufacturing Company of Alhambra, California, recently completed one of the largest soap boiling kettles which has yet been constructed entirely from nickel-clad steel for a large soap manufacturer on the Pacific Coast. The kettle, composed of four courses between its butterfly cover and conical bottom, is 15 ft. in diameter. The straight portion, from the top of the kettle to the top of the cone, is 22 ft. in height. The cone is 7 ft. high on the vertical, making a total height for the kettle of 29 ft. The cone is made from plates $^{3}/_{8}$ in. thick, while the bottom vertical course plates are $^{5}/_{16}$ in. thick, the second and third course plates are $^{1}/_{4}$ in. thick and the fourth or top course plates are $^{3}/_{16}$ in. thick. Welding throughout was done with Inco Metallic Arc Welding Wire using the arc-welding process. All of the plates are clad with pure, solid nickel on one side to the extent of 10 per cent of the total plate thickness, with black oxide finish on the nickel surface. The heating coils and the discharge spout are pure, solid nickel piping.

In the processing of fine soaps in this kettle, the fluid mixture will come in contact only with the pure nickel surface of the nickel-clad steel or the piping. This pure nickel surface is immune to rust and corrosion frequently met in ordinary steel kettles particularly at and above the liquid-air level, which conditions cause costly contamination and discoloration of the product and shorten equipment life.

Nickel-clad steel is a joint development of The International Nickel Company and our Company. The material is produced by the hot rolling and bonding of a light layer of pure, solid nickel and a heavier layer of steel. The nickel layer can be any desired proportion of the total plate thickness, from 10 per cent up. The bond of the nickel layer to the steel base is obtained through thermal diffusion which forms a solid solution alloy at the interface, and there is no separation of the layers under normal conditions of temperature changes, pressure, vacuum or mechanical shock. The material can be sheared, bent, flanged, welded or riveted without cracking or peeling and is finding application not only in soap boiling kettles and crutchers but also in storage tanks, hoppers, cooling forms, amalgamators, caustic soda tanks and other soap-making equipment.



† Manager of Alloys, Lukens Steel Company, Coatesville, Pa.

Fig. 1—Looking down the Arc-Welded Corridor Framework of One of the New Steel Dormitories Built throughout by Arc Welding

Fig. 2—Welding a Wall Corner During the Erection of One of Five New All Arc Welded Steel Buildings for Stanford University

Fig. 3—Not a Single Rivet or Bolt Was Used in Construction of Five New Steel Buildings

New University Buildings Erected Entirely by Arc Welding

By A. F. DAVIS†

REDUCTION of insurance rates because of greatly minimized fire hazard, maximum resistance to earthquakes, complete elimination of shrinkage and materially reduced time and cost of erection were all made possible by arc-welded construction of new steel buildings for Stanford University in California.

The group of new all-welded buildings, known as Lagunita Court, includes four large dormitories and one separate kitchen. The dormitory buildings, one of which is 156 ft., the other 209 ft. long, are 42 ft. 6 in. wide and two stories high.

Frames for the walls were cut to the exact length and shape, assembled in jigs in the shop and arc welded. This method made possible a rigid arc-welded connection of horizontal and vertical members at every intersection. Additional longitudinal stiffness was obtained by welding a flat diagonal strip to every stud on the outside of each panel. Not a single bolt or rivet was used.

Various members of the truss steel floor joists were assembled in jigs, and all connections arc welded in the shop. The joists were made in units the full length of the building and later shipped to the job ready to be placed in position.

† Vice-President, The Lincoln Electric Company.

Work was scheduled so that the foundations were ready for the wall panels as fabrication of the parts was completed.

Four crews of four men each placed the exterior and corridor wall panels of all four buildings in twelve days. Adjoining panels were then welded together at top, intermediate and bottom plates, producing an extremely rigid frame, highly resistant to wind stresses and earthquake shocks.

Floor joists were then welded to the exterior and interior wall studs. Placing the joists at the correct elevation was assured by a horizontal angle shop welded to all panel studs.

The design and construction of these buildings exceed all requirements of California state laws appertaining to earthquake construction. Fabrication and erection were done by the Soule Steel Company, San Francisco, California, in accordance with their standard practice for arc-welded steel frame buildings.

The welding was done in accordance with the AMERICAN WELDING SOCIETY'S standard specifications and practice, with equipment manufactured by our Company.

It is interesting to note that all work on this project was completed ahead of schedule.

High Voltage Carbon Arc Welding of Copper and Its Alloys*

By C. E. SWIFT†

HIGH voltage carbon arc welding as applied to the welding of copper simply involves the use of a high voltage or long carbon arc to melt and bring to a point of fusion with the copper a high tin phosphor bronze weld metal. It is intended here to discuss this process of welding, not only as applied to copper, but also in its application to other copper alloys such as phosphor bronze, commercial bronze, red brass and Muntz metal.

The majority of the applications of this welding procedure would be on copper, but there may be a few instances where the advantages of arc welding on bronze or brass sheets might be sufficient to warrant their use in places where they are now not used because of the difficult fabricating processes formerly employed. Where copper could be brazed in the past, the bronze and brass alloys, and more particularly the high zinc compositions, could only be oxyacetylene welded, or riveted and soft or hard soldered. Such limitations in the fabricating methods applicable to these metals undoubtedly precluded their use in many instances and forced the consumer to use a metal or alloy that could be more easily fabricated. The development of this process now makes it possible for every shop owning an arc-welding machine with sufficient current and voltage capacity to fabricate equipment of copper, brass and bronze.

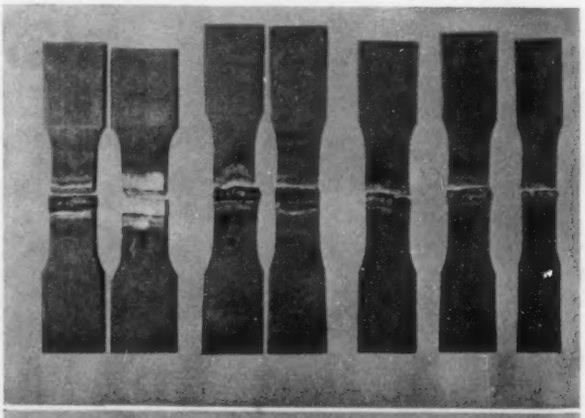
Welding of Copper

The greatest use for high voltage carbon arc welding is found in its application to the welding of copper, so I will risk a repetition for some to describe the process briefly and give a few figures on the strengths that might be expected in copper welded in this way. At this time we cannot recommend it for more than open tanks and joints in which the design stresses are low. To date, no determinations have been made of the fatigue strength across a welded joint. However, we have received no reports of failures of the numerous pieces of copper equipment welded with the carbon arc and phosphor bronze, so the test of time seems to be giving a satisfactory report.

It is necessary to supply heat to a weld faster than it can be dissipated by the adjacent metal. Due to the high thermal conductivity of copper, very high currents are required. Also, electrolytic copper when molten or above the temperature of 915° C. (1680° F.) for more than a few seconds will form accumulations of cuprous oxide at the grain boundaries. To avoid this action, a high welding speed is imperative. The molten phosphor bronze weld metal and the molten copper may dissolve gas and become porous if exposed to the oxygen of the air and to carbon monoxide, so a high voltage long arc is necessary to envelop these fused metals in a neutral atmosphere of carbon dioxide. Therefore, to obtain successful welds on copper we need a high current, a high voltage and a high welding speed.

The selection of the welding rod is important as one must be used which melts at or below the melting point of copper and can stand the high temperature involved without becoming oxidized or losing any of its constituents when superheated for a short time. After numerous tests with the available welding rods, a phosphor bronze was selected as being the most suitable for this work. The rod chosen contains nominally 10.5% tin, 0.3% phosphorus and the remainder copper. The weld metal of this rod was found to have considerably higher strength than dead soft copper (30,000 PSI), and to have sufficient ductility to withstand a flatback bend test. It is known commercially as Anaconda Phosphor Bronze, Grade "D."

Fig. 1—Broken Tensile Test Pieces, Welded Electrolytic Copper



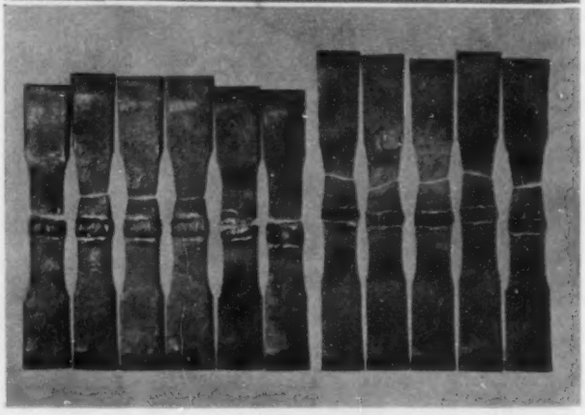


Fig. 2—Broken Tensile Test Pieces, Welded Deoxidized Copper

* Paper presented at Oct. 23rd Meeting, New York Section, A. W. S.
† Welding Engineer, American Brass Company.

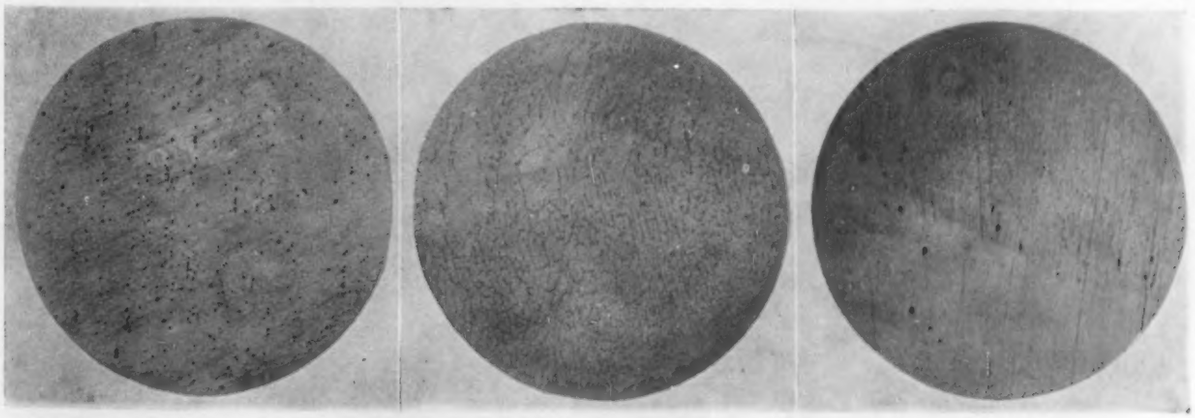
The welding procedure used with this rod and the high voltage carbon arc is substantially the same for all metals welded by this process. The plates should be beveled, if they are over $^3/_{16}$ in. thick, at an angle sufficient to allow the molten weld metal to reach the bottom of the V and, where possible, closely backed up with a comparatively light copper bar. The end of the rod should be laid in the groove and the arc struck from the rod, not from the plate. A high voltage, high current arc struck from the surface of cold copper immediately brings down a deposit of carbon black through which it is impossible to obtain adhesion of the weld metal to the base metal. This condition will exist until the copper plates are above a red heat. It is, therefore, essential at all times that the arc be maintained from the bronze weld metal. When the arc is struck from the end of the rod a pool of bronze will immediately be formed and protect the copper from deposits of carbon or surface burning. After the arc has been maintained on this pool for a sufficient length of time (not more than five seconds) to allow the heat to penetrate into the copper and bring it to the requisite temperature, this bronze will spread out on, or tin the copper, and the arc can then be advanced along the seam following the tinning of the copper with the bronze. The rod is held at only a slight angle above the surface of the plates with the end down in the bottom of the V to prevent the hot weld metal from rolling ahead on the cold base metal. It is well to select a welding rod size which will fill the vee and supply sufficient re-enforcement for the joint when an inch of rod is melted for an inch of weld. If the rod is being fed into the weld, it is often difficult to maintain a uniform bead because of the speed at which it is necessary to make these joints. A high enough current should be used on any given thickness of plate to obtain tinning of the initial pool of bronze within four or five seconds after the arc is struck. If the current value is any lower than this, the weld metal or copper will very likely be damaged before the operator is ready to advance along the seam. It has been found that any weld made slower than about 10 in. per minute will show porous weld metal and, if the plate is electrolytic copper, show oxides in the form of minute specks adjacent to the weld.

As mentioned above, it is desirable whenever possible to use a single V sufficiently wide to obtain good fusion at the bottom, and a copper back-up to support the joint. However, there are instances where this is not possible, in which case the beveled edges can be butted tightly together and a weld made at sufficient speed to avoid melting completely through the joint. If it is then possible to turn the joint over, it should be chipped out to sound metal and another light weld made. When plates are more than $^1/_4$ in. thick it may be desirable to double bevel the edges and make a first weld just fast enough to avoid melting through and then, turning the joint over, chip out unfused metal and make the second weld. When beveling copper or copper alloys prior to welding, use a generous angle, at least 45° on $^1/_4$ in. thick plates, 52° on $^3/_8$ in., and 60° on $^1/_2$-in. metal, providing respectively 90°, 104° and 120° V's. And if possible to back up the joint, do so, leaving the bottom of the beveled edges about $^1/_{16}$ in. open. Every precaution must be taken to avoid cold shuts at the bottom of the weld. Even when making lap joints, the upper copper plate should be beveled to increase to about 135° the ordinary 90° angle so obtained.

The table of test data shows what strength can be expected from properly made welds on electrolytic and deoxidized copper sheets. It is to be noted that while the strengths in both types of copper are nearly the same, a better elongation is obtained in the deoxidized copper. An examination of the specimens showed that the majority of the electrolytic copper fractures were at the edge of the weld, while the deoxidized copper broke about an inch away from the joint. (See Figs. 1 and 2.) There is also no danger of oxide segregations occurring in deoxidized copper because of slow welding, so it is the safest metal to use when copper is to be welded. Figure 3 shows the structure of an electrolytic copper sheet. Figure 4 shows an electrolytic copper sheet overheated in electric welding with cuprous oxide spread along the grain boundaries. This condition practically halves the strength of the metal. Figure 5 illustrates the appearance of the structure of a good carbon arc weld in electrolytic copper with Phosphor Bronze "D."

Welding of Brass

When welding the various grades of brass, that is, the copper-zinc alloys which include the metals commonly known as commercial bronze (90 copper, 10 zinc), red brass (80 copper, 20 zinc) and Muntz metal (60 copper, 40 zinc), essentially the same procedures as used when welding copper are to be followed. Here though, it is even more important that the maximum welding speed possible be maintained. While there is little danger of oxidation of the brasses, any continued high temperature like that of the carbon arc rapidly burns out zinc and this should be avoided. As evidenced by the fractures in joints in the various brass alloys, a certain amount of



Magnifications 75 X. Photographs Reduced to $^2/_3$ Size

Fig. 3—Structure of Electrolytic Copper Sheet Showing Scattering Cuprous Oxide Particles

Fig. 4—Structure of Electrolytic Copper Sheet Overheated in Welding. Cuprous Oxide Gathered in Grain Boundaries. Weld to the Left

Fig. 5—Structure of Good Carbon Arc Weld in Electrolytic Copper. Cuprous Oxide Particles Have Not Increased nor Moved from Place. Phosphor Bronze Weld Metal on Left

zinc is taken up by the weld metal but there is no serious porosity if the weld is made with sufficient speed The most ductility can be expected from the alloys containing the highest percentage of copper.

Tests on commercial bronze show that practically the full strength of the hot rolled sheet can be obtained in the welded joint. As usual, in tensile tests of welded specimens where the weld metal is harder than the base metal, the measure of elongation in 2 in., which includes the weld, is much lower than that of the base metal, especially where the width of the weld is any appreciable percentage of the 2 in. gage length. All fractures occurred at the edge of the weld but through the plate.

The tests on welded red brass plates show somewhat lower efficiency than that obtained on commercial bronze, but they are still sufficiently high to be of commercial value. There has been no chemical or microscopic study made of the metal at the junction of the weld and the plate, so we do not know at this time exactly what effect this high tin bronze has on the brass. The specimens failed at the edge of the weld but through the plate.

With Muntz metal it was impossible to obtain more than two-thirds of the strength of the rolled sheet across a welded joint. It was not possible with the equipment used in making these welds to obtain any higher current or arc voltage than was used, so it is not known whether an increase in these values would have improved the quality of the weld. The weld metal was sound but somewhat porous along the fusion zone with the fractures occurring at the edge of the weld, part in the weld metal and part in the plate.

No physical tests were made on phosphor bronze plates but the welds on this material showed excellent ductility and no porosity. It would be possible to fasten phosphor bronze bridge plates to steel by this method at what would probably be a considerable economy over the present method. A few experiments have shown that when making fillet welds it is best to first tin the steel with a bead of phosphor bronze and then as a second layer make a fillet weld between the phosphor bronze bridge plate and the bead of weld metal already deposited. It is quite important when depositing phosphor bronze on steel to avoid melting the steel. The bronze should be allowed to tin the steel in a simple brazing action.

This phosphor bronze welding rod may be used for coating steel surfaces for anti-friction purposes. The previously noted precaution is again mentioned, that is, the steel should not be melted under any conditions as it would flow up into the bronze and cause extreme porosity. This method of coating steel wearing surfaces has been found to offer considerable economies over the older methods now in use. Cast iron can be coated with this metal with the carbon arc if it is not soaked with grease but presents a clean, rough surface. The same general procedure is followed when builing up steel, cast iron or cast bronze with Anaconda Phosphor Bronze "D" as when welding copper, that is, the arc is maintained from the bronze at all times and advanced only as fast as the bronze tins or surface alloys ahead. Bronze deposited in this way will be found to adhere excellently to the base metals and to be sound and free from cracks.

I have not tabulated with the weld tests the current and voltages used when making the samples. They really could not be considered recommended values as

Results of Physical Tests

Gage, Inch	Tensile Strength, PSI			Elongation in 2, %			Elongation in 8 %		
	Base Metal	Weld With Bead	Weld Without Bead	Base Metal	Weld With Bead	Weld Without Bead	Base Metal	Weld With Bead	Weld Without Bead
				ELECTROLYTIC COPPER					
				(Each value given is average of two tests except for 0.202-in. gage)					
0.202	33,450	28,200	25,800	44.5	12.5	17.0			
0.164	33,000	32,350	33,300	48.5	24.3	18.0			
0.125	33,050	26,950	30,650	45.3	20.0	21.8			
0.107	32,750	30,750	....	46.8	22.8	..			
0.083	33,650	30,950	....	43.0	19.5	..			
0.062	33,550	28,000	....	44.3	16.0	..			
0.122	....	31,000	31,950	..	26.2	32.1			
Avg.	33,242	29,861	30,825	45.6	20.7	19.5			
				DEOXIDIZED COPPER					
0.186	....	30,800	....	..	40.4	..	(Avg. of 6 tests)		
0.122	....	31,080	....	..	43.3	..	(Avg. of 7 tests)		
				COMMERCIAL BRONZE					
				(90% copper, 10% zinc)					
0.200	37,100	36,500	35,800	61.0	31.0	29.0	40.0	27.0	24.0
0.200	37,300	36,500	37,300	62.0	31.0	38.0	42.0	25.0	32.0
Avg.	37,200	36,500	36,550	61.5	31.0	33.5	41.0	26.0	28.0
				RED BRASS					
				(80% copper, 20% zinc)					
								In 4 in.	
0.250	42,500	38,300	37,500	72.0	23.0	20.0	55.0	22.0	18.0
	42,800	35,100	40,000	74.0	18.0	25.0	57.0	16.0	21.0
	....	33,200	....	..	17.0	..	..	15.0	..
Avg.	42,650	35,533	38,750	73.0	19.3	22.5	56.0	17.7	19.5
				MUNTZ METAL					
				(60% copper, 40% zinc)					
0.250	44,000	31,400	30,700	74.0	16.0	15.0	56.0	16.0	14.0
	44,100	33,600	28,700	79.0	18.0	14.0	66.0	18.0	12.0
Avg.	44,050	32,500	29,700	76.5	17.0	14.5	61.0	17.0	13.0

the conditions would probably not be simulated in actual construction of equipment. I am submitting a table of currents suggested for copper of various thicknesses but the current range, as you notice, varies sometimes as much as 100%. For example, in 1/16 in. thick copper on a fillet weld 125 amperes is amply high, but when making a butt weld tightly backed up, 250 amperes is not too much. In short, the conditions of the backing and assembly of the plates permits wide variation in the current used and, as mentioned before, the best general criterion for selecting the proper current is that current value which will permit a welding speed in excess of 10 in. per minute. Fifteen inches per minute has proved to be an excellent welding speed if the welding conditions and the skill of the operator allow it. The arc voltage in any welding operation should always exceed 40 volts. At times 60 volts is not too high. These arc voltages call for an arc length of from 1/8 in. to 1 in. Too short an arc or too slow travel along the weld result in porous weld metal which is quickly evidenced by gas pockets showing on the surface.

Anticipating your questions as to the possible benefits of long arc welding on Everdur, an Anaconda alloy of copper, silicon and manganese with which you are probably familiar, I would say the principal requirement for successful carbon arc welds in Everdur seems to be the maintenance of as small a volume of molten metal as possible at any one time. This apparently prohibits the use of the long arc, as a long arc generally heats a much larger area than a short arc. While we do not admit that this is the final answer to carbon arc welding of Everdur, at the present time our findings indicate that a comparatively low current at about 20–25 volts across the arc, with a rapid weave and traverse along the joint, produces the best Everdur carbon arc welds.

Copper, Brass or Bronze Sheet Thickness, Inch	Carbon Diameter, Inch	Welding Rod Diameter, Inch	Current Amperes
1/16	1/4	1/8	125 to 250
1/8	5/16	3/16	175 to 350
1/4	3/8	1/4	250 to 500
3/8	7/16	3/8	350 to 600
1/2	1/2	1/2	600 to 800

Discussion of "An Examination of Welds Made under Field Conditions for High-Pressure, High-Temperature Steam Station Piping"* by A. E. White,† D. H. Corey†† and C. L. Clark†††

By H. N. BOETCHER**

THE severe service conditions imposed by high steam pressures and temperatures and the high degree of reliability required by a public utility power station necessitate the use of only the very best type of welds in pipe lines of such systems. In view of this condition, it is highly gratifying that the Detroit Edison Company has permitted publication of the valuable information given in the paper by Professor A. E. White and Messrs. D. H. Corey and C. L. Clark. The Detroit Edison Company is to be congratulated on the development of a method yielding welds entirely suited for the severe service. In this connection, I should like to mention the development of a practical induction type stress-relief annealing furnace by the Detroit Edison Company. This furnace is a valuable contribution to the field welding of important pressure pipe lines and seems to give highly satisfactory results in annealing both circumferential and T-welds, with accurate temperature control. The following discussion should be considered not as a criticism but as an attempt to supplement the data given by the authors of the paper.

At the time at which the Consolidated Gas Electric Light and Power Company of Baltimore, with which the writer is connected, started to examine welds systematically, we had had the benefit of many years of service experience with welds in pipe lines operating at steam pressures up to 200 lb. per sq. in. We knew that welds which had been tight and had appeared mechanically strong had failed, often after many years of service. Though not fully recognizing, at first, the effect of fatigue, we soon realized the immense importance of the soundness of the weld metal, fusion between weld and pipe and penetration. Since fatigue failures of welded joints are nearly always the result of stress concentrations which result from a neglect of these factors, or from unfavorable shape of reinforcements and similar causes, we stressed these points in the training of our welders, checking them by means of macroscopic and microscopic examinations of cross sections through welds. Just as an evaluation of welds according to tensile strength tends to direct the training of welders toward

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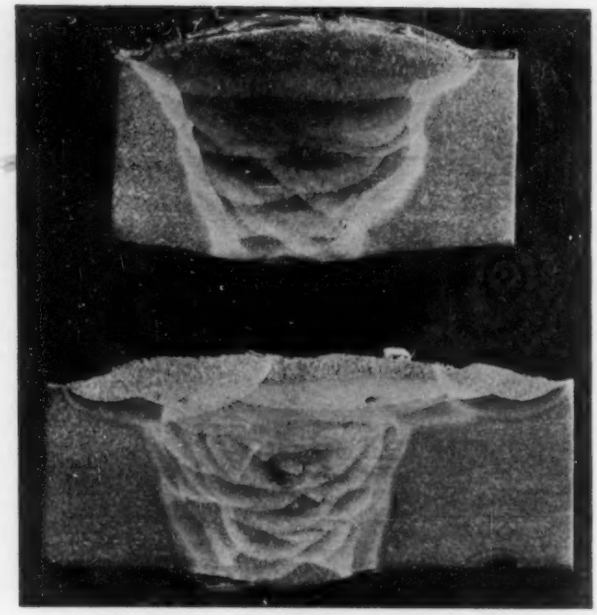
†† D. H. Corey, Drafting and Surveying Bureau, The Detroit Edison Company.
††† C. L. Clark, Research Engineer, Dept. of Eng. Research, University of Michigan.
** Asst. to Supt. of Steam Stations, Consolidated Gas Electric Light & Power Co.

Top Section



Bottom Section

Cross Sections of Welds, Polished and Etched. Top Section Stress-Relieved, Bottom Section as Welded. Magnified Approximately 2½ X

obtaining ever higher tensile strength, our method resulted in obtaining welds of increasing freedom from the factors favoring stress concentrations. Using low-carbon welding rods, we were soon able to produce oxyacetylene welds nearly perfect in this respect; in addition, the welds showed satisfactory structural properties, high ductility and very little evidence of inner stresses.

Up to the present time, we have been unable to obtain a similar degree of soundness in electric arc welds made in the field. The difficulties of obtaining consistently good *penetration* in electric arc position welds are now being overcome by the use of backing strips and by increasing the number of beads forming the weld. This latter procedure, of course, increases the possibilities of trapping pieces of slag between layers. In view of our active interest in the application of electric arc welding to pressure piping, the Detroit Edison Company gave us the opportunity to examine one of their welds and to observe the welding work then being done at the Connors Creek Station. Since lack of space does not permit the printing of a complete report on this examination, a few conclusions only will be given, especially as referring to points not dealt with in the paper and to comparisons with oxyacetylene welds.

The fatigue properties of welded joints are affected by the factors mentioned above and by the physical and structural properties of the weld and the steel. An analysis of the photograph showing polished and etched cross sections of the weld and of the Tabulations 1 and 2 will show most of these conditions.

The soundness of the weld metal is very much better than previously found in electric arc field welds though not quite as good as in our oxyacetylene welds. The weld examined by us was made some time ago and the method of cleaning has been improved in the meantime to such an extent that it now consists essentially of skimming the surface of the previously deposited weld metal before depositing the succeeding bead or layer. Since most of the inclusions were caused by pieces of slag not removed from the surfaces of previously laid-in beads, it is probable that a greater degree of soundness is obtained at present. Fusion and penetration were good, with the exception of a few small spots shown by the physical tests. The photographs indicate that a sincere attempt was made to give the reinforcement a satisfactory shape. When I was in Detroit, I noticed that care was taken not only to avoid steep edges but also to eliminate depressions as were still found in the weld which we examined.

The structural features are indicated by the photograph. The use of small beads results in low heat input. The resulting temperatures are too low to effect complete recrystallization of previously laid-in metal. Thus, about 40 per cent of the weld metal still retains an unrefined columnar structure. A further result of the low heat input at high local temperature is a quenching effect which has the most pronounced results in the pipe steel, the carbon content of which is 0.35 per cent. This quenching caused hard spots (as high as Rockwell C 38) and even some microscopic cracks. Stress-relief annealing appears to be essential to reduce the resulting inner stresses and to change martensitic and troostitic spots to sorbite.

Regarding physical properties, the ideal condition would be a weld with exactly the same properties as the unwelded pipe. It would be too much to expect the weld metal which has a carbon content of only 0.06 per cent to have properties similar to those of the medium carbon pipe. The weld metal, after stress-relief annealing, has high ductility and a high yield point. The strain hardening susceptibility is low as is indicated by the small difference between yield point and tensile strength. Tabulation 2 shows that the elastic properties of a weld machined flush with the pipe would, after stress-relieving, correspond closely to those of the pipe (specimens 3 and 7). Above the yield point, however, the strength of such a weld would be insufficient. Reinforced, the weld would be stiffer than the pipe, below the yield point of the weld metal; its plastic properties and breaking strength, however, would be close to those of the pipe as shown by specimen 13, especially when yield point and ultimate strength are calculated to the cross section of the pipe, giving 43,300 and 71,600 lb. per sq. in., respectively. The low ductility of specimens 8 to 10 is only apparent, as most of the elongation took place in the short section taken up by weld metal and as the specimens broke in the welds before the pipe steel was appreciably stretched.

A comparison of electric arc and oxyacetylene welding is bound to include a number of factors which vary sufficiently to give different conclusions under different conditions. The cost of welding is a minor consideration in this type of service and should not be the deciding factor. However, in view of certain misconceptions, it may be well to state that the idea that electric-arc welds are cheaper than oxyacetylene welds of similar quality may be based on incorrect and incomplete assumptions. A comparison made under our own conditions, with equipment available for both processes, and disregarding the costs involved in training electric arc welders to the high standing now obtained by the Detroit Edison Company, gives the following picture:

It would take one of our welders approximately eight to ten hours to make a gas weld equivalent to the one examined. A helper would be needed during part of this time only. The characteristics of oxyacetylene welding *with low-carbon steel rods* make any further treatment of the weld unnecessary.

With electric arc welding, I understand that the weld would require about sixteen hours for a welder and a helper who would be needed continuously for the cleaning and chipping. Afterward, the weld must be stress-

relieved, which process requires further time for setting up and subsequent removal of the equipment and for the heating. The stress-relieving equipment, as developed in Detroit, consists of a transformer, a control and recording apparatus actuated by the temperature at the weld, and an induction type furnace. The cost of this equipment is relatively high and would result in a high price per weld as long as the number of welds to be made is small.

This comparison is correct as long as we use pipe corresponding to Grade "A" of ASTM Specification A-106. If we go to the higher carbon contents as needed for Grades "B" and "C," conditions change in favor of electric arc welding since oxyacetylene welding causes undesirable structural changes in the steel next to the weld; these could be removed only by heating above the critical range which is rarely practical in field work. Even with electric arc welding, several problems are still unsolved. One of these is to obtain a higher carbon weld metal with properties, after stress-relieving, close to those of the pipe steel. The reinforcement now needed to give the weld sufficient breaking strength causes stress concentrations in the pipe adjacent to the weld since the lower unit stresses in the weld metal result in considerable stiffness of the weld as compared with the pipe up to close to the breaking load. With weld metal having properties corresponding to those of the pipe, it will be possible to make circumferential welds equivalent to corresponding lengths of pipe by removing the reinforcement. This is, for a different reason, already being done with many pressure vessels, and it would not be difficult to develop a suitable machine tool to do this in the field.

Another problem is the elimination of cracks which, even when microscopic, still present an element of uncertainty. Though there is some evidence that the chemical composition, as for instance the relative amounts of carbon, phosphorus and sulphur, may influence the susceptibility of the steel to cracking during welding, it is doubtful that the problem can be solved entirely by adjusting the chemical composition of pipe steel and filler material. As cracking is the result of quenching, it may be found necessary to slow down the rate of cooling in the critical range. It may be possible to do this by preheating the pipe steel next to the weld to around 1000 or 1100 F., or whatever temperature would be indicated as advisable by tests.

Tabulation 1—Bend Tests

All specimens were bent sideways. Elongations of specimens Nos. 1 to 3 refer to length of 3/4 in., of No. 4 to length of 1/4 in.

A. As received:
Specimen No. 1, 5/16 in. thick.
Opened first at slag inclusions at center at elongation of 12.5%.
Failure by splitting at root along welding line and by appearance of several cracks at elongation of 33.3%.
Specimen No. 2, 3/8 in. thick.
First crack at fusion line of beads at elongation of 12.5%.
Failure by split 3/16 in. long at elongation of 40%.

B. Annealed at 1240 F.
Specimen No. 3, 5/16 in. thick.
Small split at elongation of 30%.
No failure at elongation of 58.3%.
(Maximum elongation in 1/2 in.: 62.5%).
Specimen No. 4, 5/16 in. thick.
No failure (in 1/4 in.) at elongation of 62.5%.

Tabulation 2—Tensile Tests

Specimen	Heat Treatment	Cross-Section Area, Sq. In.	Proportional Limit, Lb./Sq. In.	Yield Point, Lb./Sq. In.	Ultimate Strength, Lb./Sq. In.	Elongation Gage Length, In.	Elongation %	Reduction of %	Notes
A. Pipe, round specimens, 2 in. gage length									
1. Longitudinal	None	0.1995	40,500	40,600	80,600	2	26.6	54.5	
2. Transverse	None	0.159	21,000	42,000	80,800	1 3/4	25.0[1]	48.8	
3. Longitudinal	1220 F	0.196	38,000	40,820	75,650	2	28.9	56.6	Modulus of elasticity 28,350,000
4. Transverse	1220 F	0.200	23,000	40,500	74,905	2	26.6	48.3	
B. All weld round specimens, transverse, 2 in. gage length									
5. Top section	None	0.154	44,000	65,000	77,100	1 3/4	17.54[1]	43.1	Three slag inclusions
6. Bottom section	None	0.154	46,000	66,700	80,390	1 3/4	19.64[1]	42.1	Fairly sound
7. Side section	1220 F	0.196	46,000	51,000	59,650	2	29.7	64.2	Modulus of elasticity 28,380,000
C. Pipe to pipe weld specimens, longitudinal									
(*a*) Round specimens, 2 in. gage length									
8. Top section	None	0.200	40,000	42,000	75,625	2	9.38	35.6	Few small inclusions
9. Bottom section	None	0.200	47,500	48,000	70,070	2	6.25	34.0	Diam. slag line, 1/16 in. wide
10. Top section	1220 F	0.200	34,000	40,000	53,860	2	6.25	16.5	Poor fusion between pipe and weld
(*b*) Flat specimens[2]									
11. Top section, machined	None	0.661	....	....	71,150	1	20.3	..	Unsound, possibly starting point
12. Bottom section, machined	None	0.657	....	....	77,380	1	23.4	..	Many small inclusions
13. Side section, not machined	1220 F	0.704[3]	....	38,450[3]	63,540[3]	2	23.4	..	Broke along depression in reinforcement

[1] The elongation in 1 3/4 in. in these specimens is equivalent to the elongation in 2 in. of standard 1/2-in. specimens.
[2] "Machined" and "not machined" refer to the removal of the reinforcement.
[3] Approximate.

WELDING SOCIETY ACTIVITIES AND RELATED EVENTS

Baltimore Section Formed

An organization meeting for the formation of a Baltimore Section was held in the Engineers' Club of Baltimore on Friday, January 11th. Mr. John H. Zink, President of The Heat and Power Corporation, acted as Chairman for the evening and introduced Professor H. L. Whittemore of the U. S. Bureau of Standards, who gave an interesting historical review of the formation of the AMERICAN WELDING SOCIETY, the research and technical work conducted by it and the many varied activities of the Society. He stressed the cooperation of the Society with the U. S. Bureau of Standards and with numerous other technical organizations. Prof. Whittemore dwelt at some length on the advantages of cooperative action in the welding industry and the desirability of discussing common problems with others interested.

He was followed by Mr. L. C. Bibber of the Bureau of Construction and Repair, U. S. Navy Dept., who delivered a very interesting general lecture on welding and cutting. Mr. Bibber reviewed the numerous tests made by the U. S. Navy and the various methods employed by it in insuring proper design, proper technique, selection of suitable materials and all of the other elements that enter into the making of a successful weld.

Discussion followed and it is expected that the formation of a Baltimore Section will be completed before many months, thus adding a new Section to the A. W. S. The Engineers' Club of Baltimore cooperated to the fullest extent in assuring the success of this particular meeting.

M. L. Eckman Appointed Research Director of Thomson-Gibb Electric Welding Company

Mr. M. L. Eckman, formerly Engineer for the Federal Machine & Welding Company and for many years prominently associated with the welding industry, has been chosen to head the Research and Development Department of the Thomson-Gibb Electric Welding Company with headquarters at Lynn, Massachusetts.

Mr. Eckman's broad experience with production welding problems includes intimate, practical knowledge gained from the standpoint of users of production welding equipment as well as designers and builders of such equipment. He was at one time associated with the Ford Motor Company and, in addition to his work in this country, has spent considerable time in Europe with both users and manufacturers of welding equipment. He is regarded as an authority on advanced welding practices in all of the leading industrial countries as well as in the United States.

At the Thomson-Gibb Lynn plant, Mr. Eckman will be in charge of a large, modern laboratory fully equipped with arc welders, butt welders, spot welders, seam welders and projection welders. Complete facilities have been placed at his disposal for the purpose of assisting manufacturers in the working out of their production problems promptly and with the assurance of the utmost efficiency and economy.

Alloys of Iron and Copper

"The Alloys of Iron and Copper," by J. L. Gregg and B. N. Daniloff, 454 pp. 6 × 9. Alloys of Iron Research Monograph Series. McGraw-Hill Book Company, Inc., New York, 1934. Price $5.00.

This is the fourth monograph of the series being published under the auspices of The Engineering Foundation and upholds the high standard of completeness and accuracy set by its predecessors. All of the research work of the world on the alloys of iron and copper, including the effect of copper on the properties and structure of plain and alloy steel and on cast iron, is adequately and concisely summarized.

Of especial interest to members of the AMERICAN WELDING SOCIETY is section E of Chapter IV which contains a complete discussion of the effect of copper on weldability. The principal investigations of the welding of copper steels and the effect of copper on the mechanical properties of the welds are those of Zeyen and Mehl in Germany, and Lorig and MacLaren in the United States whose results, including tabular matter and graphs, are summarized and discussed. These results indicate that "Weldability of steel by arc or gas methods is not impaired by copper in amounts up to 0.75 per cent or possibly more. Small amounts of copper in welding-rod metal increase the strength of the weld. The ductility as compared with that of welds made from non-copper welding rod is also increased."

Handy "Weld-O-Meter" Tells Useful Resistance Welding Facts

The "Weld-O-Meter" is a quick reference circular disc chart that tells the correct type of equipment and the right control settings to use for spot or flash welding any gage metal at any required production rate. It has just been developed and issued by the Thomson-Gibb Electric Welding Co., of Lynn, Mass.

The "Weld-O-Meter" is ingeniously designed so that a single turn of the disc tells all of the information at a glance. On one side, the chart tells the type welder required, the transformer capacity, the heat regulator setting and the pressure needed to spot weld metals ranging from two thicknesses of 26 gage up to two thicknesses of $1/4$-in. stock at production speeds of from 30 to 120 spots per minute of the lighter gages to 5 to 20 on the heavier stocks. The spot welding chart tells the current consumed per 1000 welds in kilowatt hours and suggests an alternative welder for the same work.

The reverse side of the chart tells similar information about the equipment needed to butt or flash weld metals ranging from 0.01 sq. in. to 2 sq. in. in cross-section area. Complete information on the type welder, the proper clamping and push-up devices, the transformer capacity, heat setting and push-up pressure, as well as the current consumed and the production per hour, is shown when the dial is set at the point on the chart which represents the area of the metal to be welded. Pictures of the different types of welders are also shown on both the spot and flash sides of the "Weld-O-Meter."

Membership

The Membership Committee of the Society is launching an intensive drive for new members. It has set a goal of 2000 members before the Annual Meeting. The cooperation of everyone identified with the welding industry is urgently desired in making this drive a success. The greatest need is in the names of real live prospects. Members are urged to send in as many of these as possible. The Membership Committee will do the rest.

Annual Meeting

The Meetings and Papers Committee have held a preliminary meeting to discuss plans for the Annual Meeting of the AMERICAN WELDING SOCIETY. In order to provide an unusually important Fall Meeting, the Committee has suggested that the Annual Meeting program be confined very largely to a business session with meetings of technical and other committees of the Society.

Plans are under way by the New York Section for holding a joint meeting with the local chapter of the American Society for Metals at the Hotel Pennsylvania on Wednesday Evening, the day preceding the Annual Meeting of the Society. The next issue will contain details of this meeting.

The business session as provided for in the by-laws will be held Thursday, April 25th. In addition to technical committees there will also be a meeting of the Board of Directors.

Symposium on the Welding of Iron and Steel

A Symposium on the Welding of Iron and Steel under the auspices of The Council of the Iron and Steel Institute in the Hall of the Institution of Civil Engineers, Great George Street, London, S.W.1, May 2 and 3, 1935, and will be divided into four sessions. The papers will be divided into twelve groups and subgroups. The groups and sub-groups will consist of: (1) Present-Day Practice and Problems of Welding in the Engineering Industries—Aeronautical Industry; Agricultural Engineering Industry; Automobile Industry; Chain Manufacture; Electrical, Heavy Engineering and Machinery Manufacturing Industries (including Marine Engineering); Pressure Vessels (including Boilers, Pipe Lines, Tubes, Tanks and Vessels for Use at High Temperatures and Pressures); Railway Material; Shipbuilding; Structural and Bridge Engineering. (2) Welding Practice and Technique—Influence of Fine Beads; Layer Welding and Bead Welding; Methods for Vertical and Overhead Welding; Relieving of Stress and Methods of Avoiding Distortion of Welded Structures. (3) The Metallurgy of Welding—the Absorption and Evolution of Gases during Welding and Their Effects; the Chemical Composition of the Rod and the Welded Material and Changes in Composition on Welding; Covering for Rods; Welding of Special Steels. (4) Specification, Inspection, Testing and Safety Aspects of Welding. (5) Current Research Projects in Welding.

SECTION ACTIVITIES

BOSTON

Mr. Everett Chapman, Vice-President of Lukenweld, Inc., spoke before this Section on Friday evening, January 18th. Mr. Chapman spoke on the experiences of Lukenweld, Inc. in fabricating with welding, and about the photoelastic studies they have made to analyze stresses in welds. This talk was illustrated. The meeting was held in Room 5-330, Massachusetts Institute of Technology, at 7:30 P.M.

CHICAGO

A meeting of the Chicago Section was held at the Milwaukee School of Engineering Hall, Milwaukee, Wis. on December 14th. "The Welding of Stainless-Clad Steel" was the subject of an illustrated talk by Wm. B. Keelor of the Ingersoll Steel & Disc Company. Mr. Otto C. Voss showed pictures of some of the interesting work being done in the welding department of the Allis-Chalmers Plant in West Allis. There were between 350 and 400 present at this meeting.

The regular meeting was held on December 28th at the Morrison Hotel, Chicago. "Low Temperature Brazing Alloys" was presented by Alden W. Swift, of Handy & Harman. "A Study of the Metallic Arc," with motion pictures, was presented by Robert W. Holt of the Chicago Steel & Wire Company.

CLEVELAND

The third regular monthly meeting of this Section was held at Cleveland Engineering Society on Wednesday, January 9th. Mr. K. L. Hansen, Designing Engineer, The Harnischfeger Corporation, spoke on "Modern Arc Welding and Its Application."

DETROIT

On December 5, 1934, the Detroit Section held a joint meeting with the Industrial Electrical Engineering Society at the Fort Shelby Hotel, Detroit. Mr. J. F. Lincoln, President of the Lincoln Electric Company, addressed the meeting. In a well illustrated lecture, he pointed out the differences between arc welding with bare wire and with the shielded arc.

During the discussion that followed the lecture, Mr. Claude A. Bowlus, explained the current application of arc welding to die fabrication and maintenance.

At the joint meeting 103 members and their guests attended the dinner, presided by R. P. Bailey, Chairman, Detroit Section. The attendance at the lecture was about 175.

Mr. W. H. Ludington, Manager Applied Engineering, Air Reduction Sales Company, addressed the January 9th meeting of the Detroit Section, on "Some Practical Aspects of Machine Gas Cutting in Modern Fabrication." This was fully illustrated by slides and exhibits. Interesting applications of gas welding were shown by moving pictures.

NEW YORK

A joint meeting of the New York Section of the A. W. S., and Power and Iron & Steel Divisions of the American Society of Mechanical Engineers, was held on Monday, January 14th in the Engineering Societies Building. The meeting was devoted to a "Symposium on Recent Developments in Welded Pressure Vessel Construction." Mr. J. C. Hodge of Babcock & Wilcox Company, spoke on "Non-Destructive Testing of Welded Joints, Its Development, Practice and Limitations"; Mr. R. H. Hopkins of M. W. Kellogg Company, spoke on "Physical Properties of Fusion Welded Joints as Produced by Manufacturers of Class I Pressure Vessels"; and Mr. A. C. Weigel, Combustion Engineering Corp., spoke on "Corrosion Resistance Tests of Welded Pressure Vessels."

PHILADELPHIA

The following is the winter and spring schedule of meetings for 1935 of the Philadelphia Section:

Thursday, January 24, 1935—Joint meeting with the Franklin Institute—"Practical Demonstrations of Welding and Cutting."

Monday, February 18, 1935—"Welding in the Ship Yards."

Monday, March 18, 1935—"Stress Analysis."

Monday, April 15, 1935—"Welding as Applied to Air Conditioning."

May 1935—INSPECTION TRIP. The date and full particulars will be announced at some future meeting.

January Meeting at Franklin Institute, 20th & Parkway.

All other meetings at Engineers' Club.

All meetings scheduled for 8 P.M.

SAN FRANCISCO

The December meeting of this Section was held on the 14th at the Athens Athletic Club. Mr. S. Cozzo, Engineering Department of The Western Pipe and Steel Company, addressed the meeting on "Economies of Welding." Mr. S. H. Taylor of The Lincoln Electric Company, showed a Polariscope which projects images upon a screen of specimens under stress. Mr. C. B. Leahy of the Air Reduction Sales Company, discussed some of the outstanding articles which recently appeared in the Society JOURNAL.

EMPLOYMENT SERVICE BULLETIN

SERVICES AVAILABLE

A-206. Mechanical Designer on welded fabrication with thorough training in welding, six years' shop experience in welding. Also interested in temporary assignments or will prepare designs at his home.

United States Civil Service Examination

The United States Civil Service Commission has announced an open competitive examination as follows:

MASTER MECHANIC, AIRCRAFT-ENGINE MANUFACTURE

Applications for the position of Master Mechanic, Aircraft-Engine Manufacture, Naval Aircraft Factory, Philadelphia, Pa., must be on file with the U. S. Civil Service Commission at Washington, D. C., not later than January 1935.

The rate of pay ranges from $11.04 to $17.04 a day, subject to a deduction of not to exceed 5 per cent during the fiscal year ending June 30, 1935, as a measure of economy, and also to a deduction of $3\frac{1}{2}$ per cent toward a retirement annuity.

Certain specified experience is required.

Full information may be obtained from the Secretary of the United States Civil Service Board of Examiners at the post-office or customhouse in any city which has a post-office of the first or the second class, or from the United States Civil Service Commission, Washington, D. C.

CURRENT WELDING LITERATURE

Aluminum. Electrical Process for Welding Aluminum. Engineer (Nov. 23, 1934), vol. 158, no. 4115, p. 522.

Automobile Body Manufacture. Wide Sheets for Streamline Bodies Produced by Special Flash Welder, P. W. Fassler. Iron Age (Sept. 20, 1934), vol. 134, no. 12, pp. 38–39.

Beams. Investigation of Web Buckling in Steel Beams, I. Lyse and H. J. Godfrey. Am. Soc. Civ. Engrs. Proc. (Nov. 1934), vol. 60, no. 9, pp. 1354–1359.

Cutting Tools. Superweld Tools. Edgar Allen News (Dec. 1934), vol. 13, no. 151, pp. 55–58.

Electric Welding, Arc. How to Cut Maintenance Costs by Arc Welding, A. Madson. Mill & Factory (Sept. 1934), vol. 15, no. 3, pp. 50–51 and 108 and 110. Arc welding permits immediate repair of broken and worn parts at cost far below that of replacement; examples given of welding jobs on brake flanges, cast-iron boiler, gear wheel, bending brake and curved conveyor track.

Electric Welding, Arc. Lower Welding Costs, E. W. P. Smith. Am. Mach. (Sept. 26, 1934), vol. 78, no. 20, pp. 665–667. Use of larger electrodes frequently means lower charges for power; labor and overhead; curves showing relation between electrode size and number of interruptions; elements of cost compared to electrode size shown in tables and curves.

Electric Welding, Arc, Electrodes. Arc Welding by Metallic Electrode Process, H. Thomasson. Elec. News (Nov. 15, 1934), vol. 43, no. 22, pp. 33–34. Advantages of coated electrodes; notes on shop tests and butt welds.

Electric Welding, Arc, Electrodes. Improved Arc Welding and Electrodes. Metal Progress (Oct. 1934), vol. 26, no. 4, pp. 143–146 and 148.

Electric Welding, Resistance. Spot Welding, L. Ferguson. Bell Laboratories Rec. (Dec. 1934), vol. 13, no. 4, pp. 109–112. Welding characteristics of some 250 combinations of metals studied in laboratories; outline of welding process; application to vacuum tubes and telephone equipment.

Electric Welding, Resistance. Shot Weld Closely Controlled Welding Process, W. Spraragen. Iron Age (Sept. 27, 1934), vol. 134, no. 13, pp. 18–21. Facts and figures on so-called shot welding which is high-speed spot-welding operation according to new method which produces in material being welded, certain desirable metallurgical and physical characteristics; various applications, including application in light-weight cars.

Industrial Plants. Production Methods in Pipe Welding for Plant Construction, G. E. Deatherage and J. B. Latterner. Heating, Piping & Air Conditioning (Dec. 1934), vol. 6, no. 12, pp. 500 and 505. Welding has made practicable "made-to-measure" fabrication and erection of complete piping job; six factors around which plan of operation is laid in chemical plant discussed.

Locomotives, Mine. Rebuilding Mine Locomotive Tires, R. D. Eaglesfield. Coal Min. (Oct. 1934), vol. 11, no. 10, p. 81. Notes on advantages of electric arc welding for reclaiming worn, damaged and broken parts; cost figures for rebuilding 26-in. tires; labor, material and power cost $7.38 as against $30 for new wheel.

Oxyacetylene Cutting. Flame Machining—Its Effect on Steel, E. E. Thum. Metal Progress (Dec. 1934), vol. 26, no. 6, pp. 35–39.

Oxyacetylene Welding. Advances in Oxyacetylene Welding. Metal Progress. (Oct. 1934), vol. 26, no. 4, pp. 139–142.

Penstocks. Failure of Steel Penstock under Test at Hawk's Nest Hydro Plant Kills Five Men. Eng. News-Rec. (Nov. 8, 1934), vol. 113, no. 19, p. 604. Details of catastrophic test failure of 14-ft. electrically welded penstock of hydroelectric plant of Electro Metallurgical Co. on New River near Gauley Junction, W. Va.

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Petroleum Pipe Lines. Welding Iraq Pipe Line, W. Schack. Oil Weekly. (Oct. 22, 1934), vol. 75, no. 6, pp. 35–36. Note on detail in welding practice; line is composed principally of 12-in. pipe, 0.33 in. thick in 40-ft. lengths.

Pipe Lines. New Records in Pipe-Line Welding, R. B. Miller. Gas Age Rec. (Oct. 20, 1934), vol. 74, no. 16, pp. 333–334 and 336. Notes on results obtained in oxyacetylene welding, using new type of blowpipe head.

Power Plants. New Building Form Introduced by Mercury-Steam Power Plant, D. A. Allee. Eng. News-Rec. (Nov. 8, 1934), vol. 113, no. 19, pp. 585–589.

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Pressure Vessels. Automatic Arc Welding for Pressure Vessels, O. A. Tilton. World Petroleum (Dec. 1934), vol. 5, no. 12, pp. 462–464.

Pressure Vessels. Industrial Process Piping, L. P. Hynes and W. Schoeni. Heating, Piping & Air Conditioning (Nov. 1934), vol. 6, no. 11, pp. 463–466 and (adv. section) 75.

Pressure Vessels. Lloyd's Register of Shipping Adopts Tentative Requirements for Fusion Welded Pressure Vessels. Boiler Maker & Plate Fabricator (Nov. 1934), vol. 34, no. 11, pp. 295–298.

Rolling Mills. Japanese Steel Equipment Fabricated by Arc Welding, A. F. Davis. Iron Age (Sept. 20, 1934), vol. 134, no. 12, pp. 33–34.

Sheet Metal Working. Modern Sheet Metal Welding. Oxy-Acetylene Tips (July 1934), vol. 13, no. 7, pp. 149–153.

Shielded Arc Electrodes. 8-Page pamphlet published by the Air Reduction Sales Company, New York, describing their new Shielded Arc Electrodes. Copies may be obtained on request.

Shipbuilding. Riveting and Arc Welding in Ship Construction, H. E. Rossell. New York, Chicago and San Francisco, Simmons-Boardman Publishing Co., 1934. 210 pp., diagrs., charts. Author discusses riveted and arc-welded joints from both practical and theoretical points of view with special reference to ship design and construction.

Shipbuilding. Welded Ship Construction, D. Arnott. Mar. News (Dec. 1934), vol. 21, no. 7, pp. 44–47 and 110. Abstract of paper before Soc. Naval Architects & Mar. Engrs.

Steel Structures. Structural Design in Steel, T. C. Shedd. New York, John Wiley & Sons, 1934. 560 pp., illus., diagrs., charts, tables. Account of fundamental principles that underly all design in structural steel accompanied by illustrations of their application in practice; includes descriptions of ordinary bridges and building frames; design of three primary structural forms and their connections; design of buildings and bridges and structural welding.

Steel Testing. Lower Yield Point in Mild Steel, B. P. Haigh. Engineering (Nov. 2, 1934), vol. 138, no. 3590, pp. 461–464; (Nov. 16), no. 3592, pp. 544–545. Nov. 2—Specification and measurement of low yield point; application in calculations and in design and welded beams. Nov. 16—Application in design of welded penstocks. Before Brit. Assn.

Tantalum. Arc Welding of Tantalum Sheets. Metal Industry (Lond) (Nov. 16, 1934), vol. 45, no. 20, p. 466. Important factors which must be considered in working with tantalum.

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Tubes. Oxy-Acetylene Welding of Steel Tubes, G. Calbiani. Metallurgist (Oct. 26, 1934), pp. 167–171.

Water Pipe Lines. How to Thaw Frozen Pipes with Electric Welder. Domestic Eng. (Chicago) (Dec. 1934), vol. 144, no. 6, pp. 44–45 and 132.

BOOKS

Arc Welding Electrodes for Stainless Steel—A new booklet issued by Arcos, Inc., 401 North Broad Street, Philadelphia, which gives instructions for welding stainless steels, also chemical analyses, weights of Chromend Stainless Electrodes and many other facts pertinent to stainless steel welding.

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